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GEOLOGICAL MAGAZINE

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The Development of a Diplograptid from the Platteville Limestone

By MARGARET WALKER

ABSTRACT

This paper describes the development from the initial prosicula of the rhabdosome of *Diplograptus* cf. (*Amplexograptus*) *maxwelli* Decker. Points of comparison with other diplograptid astogenies are noted. Evidence about the structure of the interthecal septum is brought forward and so stages in the formation of one thecal segment can be defined. Mention is made of some abnormal specimens.

INTRODUCTION

THE material described below has been obtained from specimens of Platteville Limestone collected in Lancaster, Wisconsin, U.S.A. The limestone is of Black River age, containing a shelly fauna of brachiopods as well as material preserved in chitin.[1] Almost the whole of the latter consists of *Diplograptus* cf. (*Amplexograptus*) *maxwelli* Decker in various stages of development. The rest of the fauna comprises the fairly common *Rhabdochitina*? *minnesotensis* Stauffer (SM. A 49688–91), the polychaete jaws *Staurocephalites dentatus* Stauffer (SM. A 40686–7) and *Lumbriconereites* cf. *cameratus* Stauffer (SM. A 40686) and fragments of an indeterminate dendroid.

The originals of the figured specimens have been placed in the Sedgwick Museum and bear the Museum's catalogue numbers.

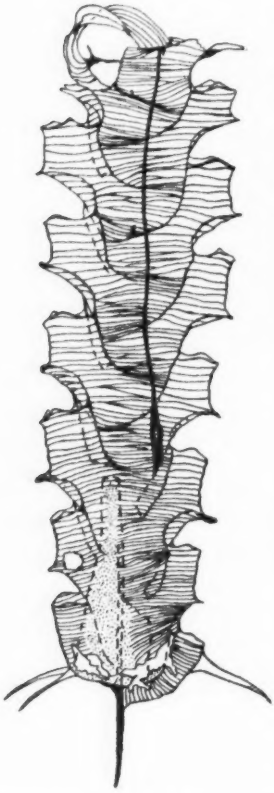
DESCRIPTION (see Text-fig. 1)

Rhabdosome small, up to 14 mm. in length. Initial width at th1[2] 0·7–0·8 mm., widening gradually to 1·2 or 1·3 mm. Sicula 1·4 mm. long, of which 0·9 mm. can be seen on the obverse side, with a short but conspicuous virgella and two apertural spines. Prosicula prolonged into a virgula which extends up the axis of the rhabdosome. Thecae

[1] The term "chitin" is employed throughout for convenience, and its use does not imply exact knowledge of the substance forming the graptolite rhabdosome.

16–14 in 10 mm., with the ventral walls parallel to the axis and undulate apertural margins. The first theca bears a spine. The excavations of the first few thecae are about 0·3 of the free ventral wall, but distally widen to 0·4 and then 0·5 and become more oblique. Overlap 0·35 proximally to 0·45 distally.

This species corresponds closely in general form with *D.* (*Amplexogr.*) *maxwelli* as described by Decker (1935) and Decker and Frederickson (1941), but its dimensions are rather smaller than those given by them for that species. From an examination of their illustrations it would seem that the figures given are for the largest specimen known (1935, pl. 1, figs. 1, 1*a*; 1941, pl. 27, fig. 1), and that the usual size is smaller. Thus the species described here approaches more closely to Decker's species than is at first apparent although the two still do not exactly correspond. Both occur at the same horizon, the Platteville Limestone (Decker and Frederickson, 1941).



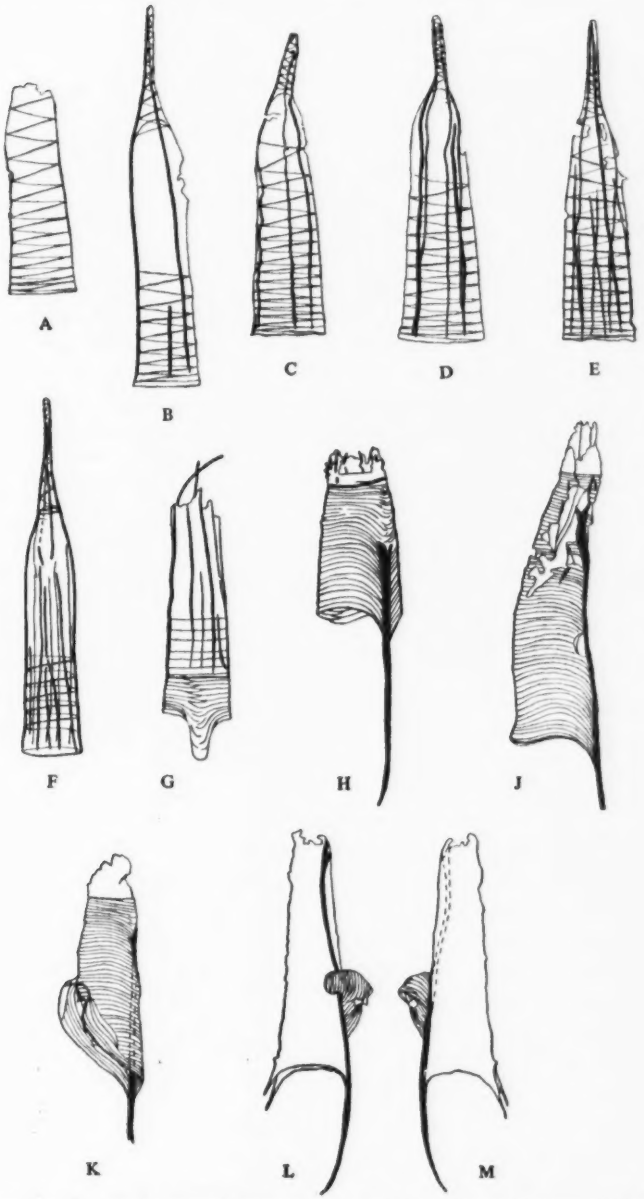
TEXT-FIG. 1.—Rhabdosome of *Diplograptus* cf. (*Amplexograptus*) *maxwelli* Decker. × 22 approx. S.M. A24298.

In view of the wide excavations between the thecae the species is probably best assigned to the sub-genus *Amplexograptus*, although the rhabdosome does not show a concavo-convex cross-section. This feature, together with the shape of the thecae, was originally made the basis of the group by Lapworth, Elles, and Wood (1901–1918, p. 218), but seems to have been largely ignored in later work and may prove to be a preservational effect. If this were so, the form which Cox called *Climacograptus inuiti* would more properly be an *Amplexograptus*, since it has similar wide excavations (Cox, 1933, p. 2).

DEVELOPMENT

Prosicula.

The earliest stage seen is a bottle-shaped prosicula 0·5 mm. in length which shows the characteristic spiral thickening: widely spaced near the top where the chitin is correspondingly very thin and



TEXT-FIG. 2.—Early growth stages of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. A-F, prosicula ; G–K, metasicula ; L and M, initial bud, reverse and obverse sides. A–H × 55 approx. ; J–M × 35 approx. SM. A24274 to 24284.

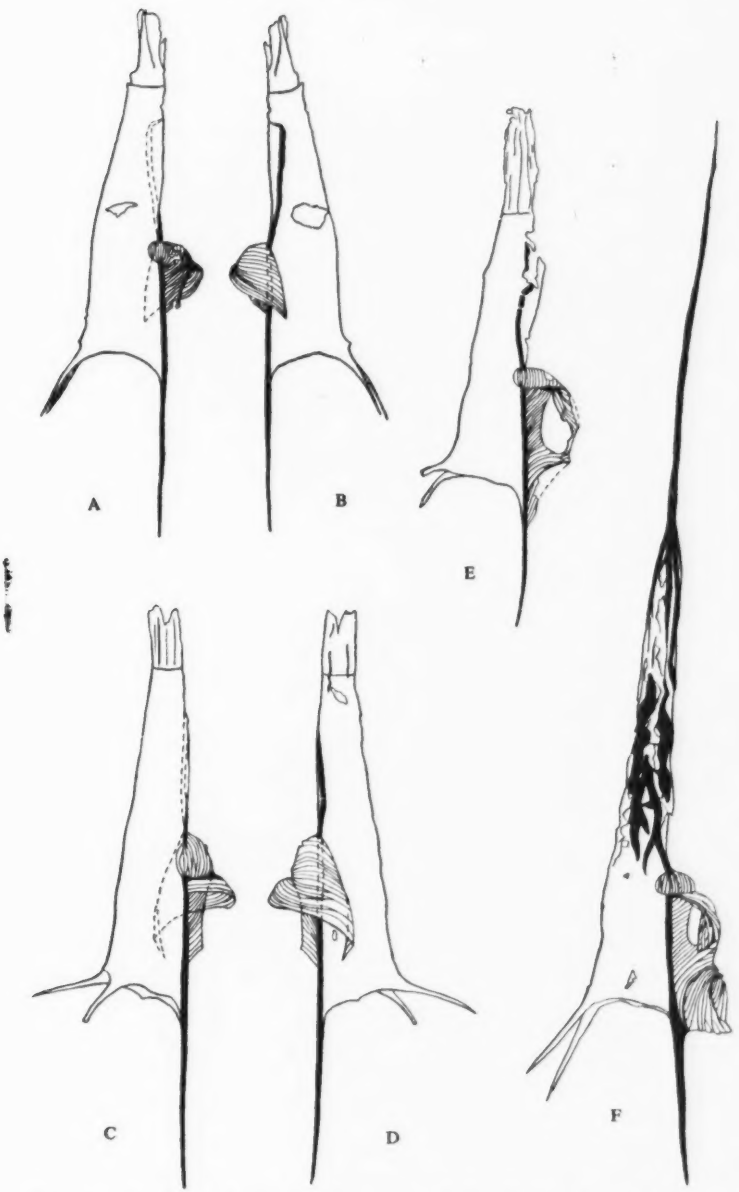
usually torn, but becoming sub-parallel near the aperture where the wall is thicker (Text-fig. 2A). The majority of specimens have a right-handed spiral ; a few show one in the opposite direction. In later forms where the neck is preserved, this spiral can be seen to extend right to the tip of the prosicula. In some of them also a darkening in the chitin with a concave margin is seen at the beginning of the neck ; an appearance like the " membrane " of Kraft (Text-fig. 2B, C, D). Whether in fact this is such a structure is not known : if complete, it would separate the nema from the main part of the prosicula, and further growth of each section would be by the agency of different parts of the organism. These following stages show the growth of longitudinal (? strengthening) rods along the prosicula, which extend almost, but not quite, to the apertural margin. They appear to be produced successively since specimens with almost all numbers of rods up to twelve are found. Only the first four rods extend into the nema ; later ones reach either the beginning of the narrow part, or some 2/3, or a few 1/3, along the length of the prosicula (Text-fig. 2D, E, F). There is thus little evidence that the first rods grew from nema to aperture, as Kraft thought, since not only these but also the shorter ones fade out before reaching the aperture. Indeed, if Text-fig. 2B be considered as a normal stage between the formation of rods two and three, it would indicate a direction of growth from aperture to tip. The final number of rods is variable but is usually about ten or twelve.

Metasicula.

Next, chitinuous material is laid down round the apertural margin of the prosicula, in half rings which alternate on one side and the other. These overlap at the tips, thus forming two zig-zag sutures on opposite sides of the metasicula. About the first six complete rings show an almost straight margin, but then along one side a projection is formed by the widening of each half ring at this point. This is the beginning of the virgella (Text-fig. 2G). From about the twelfth growth line of the metasicula, that is, about 0·15 mm. along its length, the growth lines on the virgella cannot be seen due to thickening, but it forms a marked spine which projects from the margin of the metasicula. Successive rings increase in diameter, giving the sicula its characteristic conical shape (Text-fig. 2H).

Initial Bud.

A circular foramen appears in the wall of the metasicula, on the reverse side next to the virgella, before the metasicula has reached maturity. It must have been formed by resorption, since it cuts across about six growth lines (Text-fig. 2J). The margin becomes thickened and half rings of chitin are laid down on the side opposite the virgella so that a hood grows over to the obverse side of the sicula.



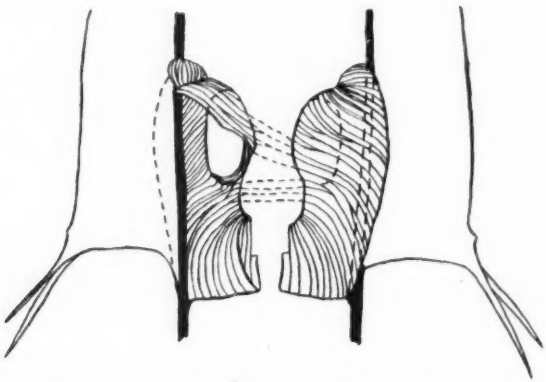
TEXT-FIG. 3.—First theca growth stages of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. All reverse face except B and D (obverse). All × 35 approx. SM A24285 to 24288.

Further half-rings and wedges are added so that the bud turns downwards, and one margin grows down the virgella (Text-fig. 2L and M).

During this time material has also been added to the sicula. In the prosicula some of the rods are much thicker and the nema has become longer (Text-fig. 3F); while further growth bands have been added to the margin of the metasicula, producing opposite the virgella a notch bordered by the apertural spines (Text-fig. 2L and M, 3A and B).

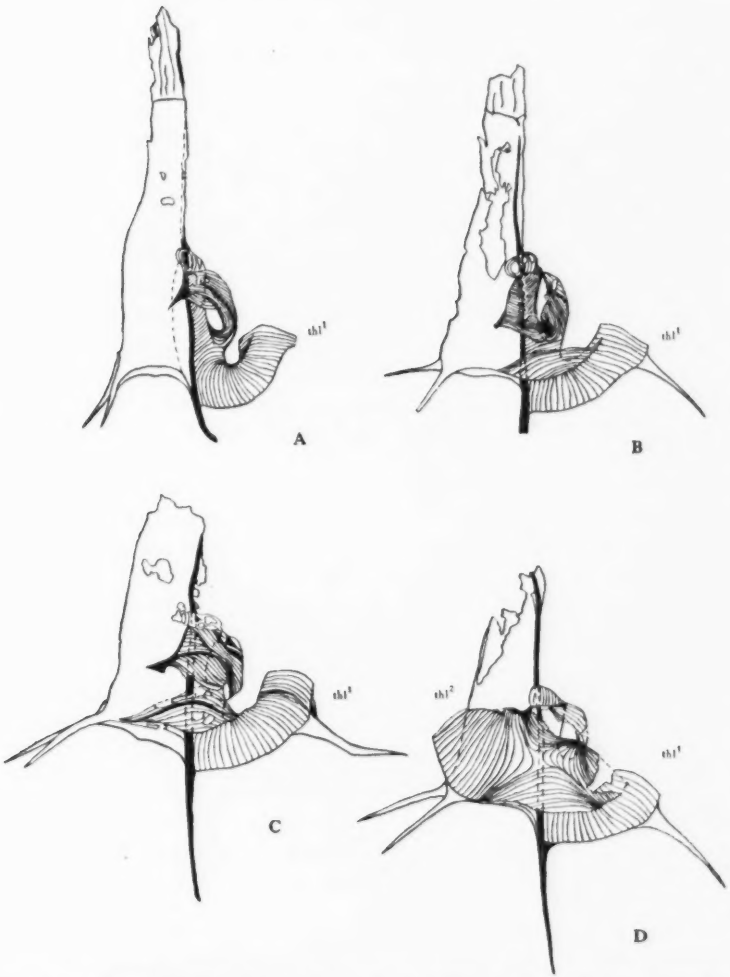
The First Theca.

A foramen is now initiated as a notch by the addition of strips of chitin along the virgella which are separate from the material



TEXT-FIG. 4.—*D.* cf (*Amplexogr.*) *maxwelli* Decker. Stage showing initiation of second theca, reverse and obverse sides. × 55 approx. SM. A24289.

added at the other side (Text-fig. 3A and B). The latter at first takes the form of wedges so that the aperture comes to point more laterally, but then the upper edge begins to grow across the reverse side towards the virgella (Text-fig. 3C, D, E). The condition seen in Text-fig. 3C and D is somewhat unusual in that this edge has reached the virgella and grown down it before the foramen is complete—a more usual case is seen in Text-fig. 3E. The foramen is completed when the chitin of the obverse side no longer extends across the hood to the initial bud, but joins up, by a zig-zag suture with the strips on the reverse side (Text-fig. 3E). Th1[1] then continues to grow down the virgella. At the level of the aperture of the metasicula it turns outwards and then upwards, producing a spine on the outer margin which is not usually marked by any change in the spacing of the growth lines (cf. *Climacograptus inuiti* Cox, 1933). After this two or three more bands are added and the theca is complete (Text-fig. 5A, B).



TEXT-FIG. 5.—Second and third theca growth stages of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. All reverse side. × 35 approx. SM. A24290 to 24293.

The Second Theca.

The foramen formed as described above is that of th1². Further growth of this theca continues with narrow strips of chitin extending from the margin of the hood to the edge of the foramen, filling in a triangular space (Text-fig. 4). About the third or fourth strip occupies the whole length of the hood margin, reaching the initial bud as before. There is thus an "unconformity" between these chitin

bands of th1^2 and the previous ones, and the place of change shows a thickened growth line in many specimens. It is probable that this marks the beginning of formation of chitin by individual 1^2—perhaps after a brief period of no growth, for although both thecae were growing concurrently the rate of growth of th1^1 must have been considerably greater than that of th1^2 (cf. Text-fig. 3E, F, and 5A).

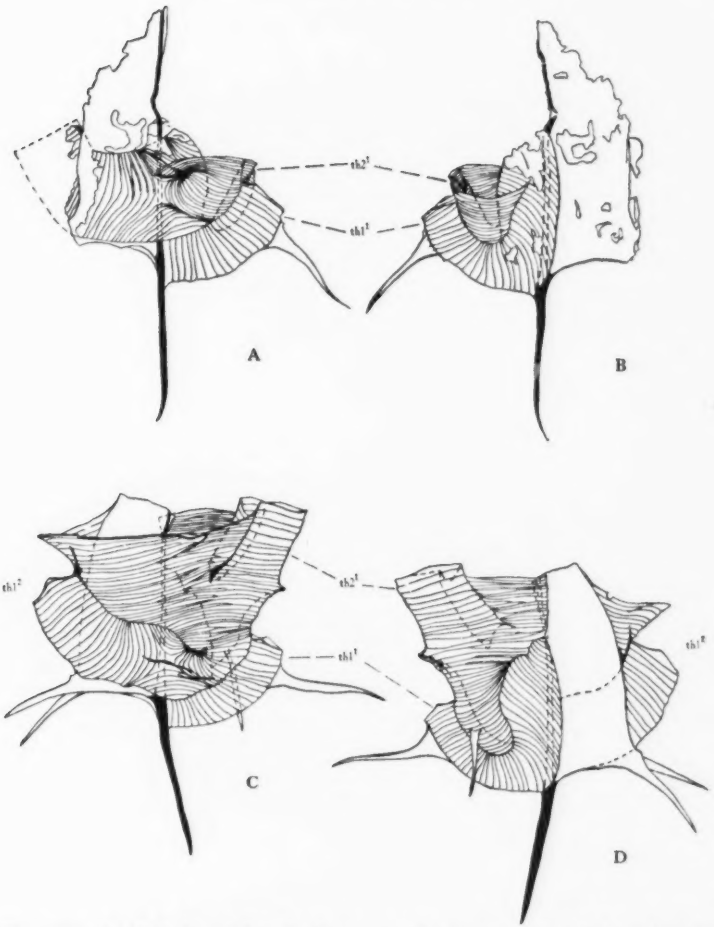
Th1^2 continues to grow as a hood covering the foramen, with one margin extending across the reverse face of the sicula (Text-fig. 5A). In most cases the strips wedge out at the other side in the angle of the foramen and thus growth pivots round this point (Text-fig. 5B). In some (e.g. Text-fig. 3F) a few strips are attached to the wall of th1^1 and so the pivot lies just below the angle of the foramen. The margin of the hood becomes lobed, and at the same time bands of chitin are deposited from the lower margin of the sicula across to the inner part of th1^1, growing up to meet the lobe (Text-fig. 5B). When the two meet, further chitin bands are added laterally on both sides (Text-fig. 5C and D). Those forming th1^2 (on the left in the diagrams) are long strips extending right across the width of the theca ; the others (on right in diagrams) are at first short, reaching from the pivot to the edge of the lower lobe, and only later ones extend the whole width of the theca. Thus there is again an " unconformity " at the base of the new theca, as this side forms the beginning of th2^1. The other side, without the unconformity, is merely continued growth of th1^2. The latter grows across the reverse face of the sicula, the chitin rings extending further and further round as it becomes free from the sicula (Text-fig. 5D). Finally it extends upwards as a short parallel-sided tube, with a slightly undulate apertural margin (Text-fig. 6C).

The Third Theca.

Meanwhile th2^1 grows up the inner part of th1^1, at first only on the reverse side (Text-fig. 5D). Later, material is added on the obverse side also, filling in the space between the two limbs of the first theca, and both parts join up with the usual zig-zag suture when the aperture of th1^1 is left behind (Text-fig. 6B). About this time the other margin of th2^1 on the reverse side begins to grow across the earlier-formed lobe of th1^2 (Text-fig. 6A). It continues up the inner margin of th1^2 and so crosses the sicula, the chitin bands becoming very long in consequence. At this level an interthecal septum between th2^1 and the next theca begins, thus marking the base of th2^2 (Text-fig. 6C). From this point th2^1 grows upwards, the change in direction of growth sometimes being marked by a flange on the ventral wall which is characteristic of successive thecae (Text-fig. 6C, D, and 7A, B).

The Fourth Theca.

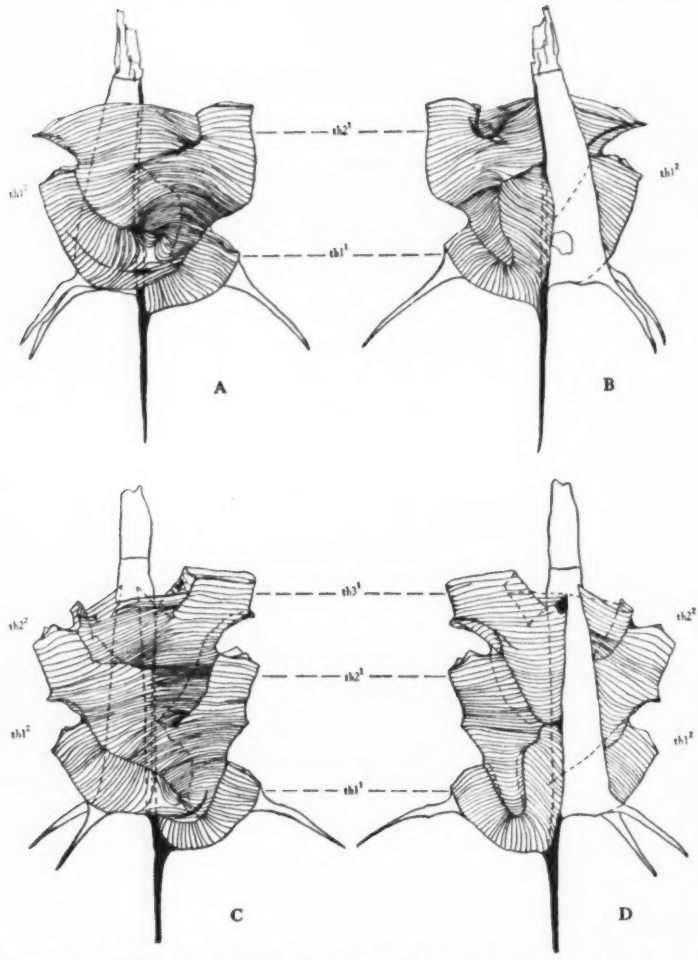
The deposition of chitin by individual 2^2 continues the wall begun



TEXT-FIG. 6.—Third and fourth theca growth stages of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. A, C, reverse side, B, D, obverse side. × 35 approx. A, B, SM. A24294. C, D, slide subsequently damaged.

by individual 2^1 across the reverse face of the sicula, the place of change sometimes being marked by a very slight " unconformity " in the growth bands. The chitin bands are long and join the dorsal wall of $th2^1$ at one end (Text-fig. 7A). On the obverse side the theca is completed by two series of short strips, one stretching between the dorsal wall of $th2^1$ and the sicula, and the other between the sicula and the ventral margin of $th2^2$ (Text-fig. 7B). Here the two sides join with a zig-zag suture when the aperture of the previous theca, 1^2, has been passed.

On this theca also a flange is formed as the direction of growth



TEXT-FIG. 7.—Fourth and sixth theca growth stages of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. A, C, reverse side, B, D, obverse side. × 30 approx. SM. A24295 and 24296.

changes and in the complete theca the undulate apertural margin is seen (Text-fig. 7C, D).

Successive thecae are formed in a similar way to that described above for th2² (Text-fig. 7C, D). At about the base of th3² the chitin bands on the obverse side extend right across the sicula, so that distal to this the axial walls of the rhabdosome are continuous on both sides (Text-fig. 8). The tip of the sicula and the virgula into which it is prolonged are thus enclosed and lie free inside the common canal

except for occasional attachments to the lateral walls of the rhabdosome (Text-fig. 1).

Throughout the rhabdosome can be seen the problematical irregular markings on the walls which were called by Kraft " chitin thickening bands ".

It is interesting to note that the straight parts of the thecae, above the flange, successively comprise fewer growth bands, and also become shorter, although the bands of the first two or three thecae are closer

TEXT-FIG. 8.—Outline drawing of *D.* cf. (*Amplexogr.*) *maxwelli* Decker, showing the enclosure of the tip of the sicula in the cavity of the rhabdosome. Obverse side. × 22 approx. SM. A24297.

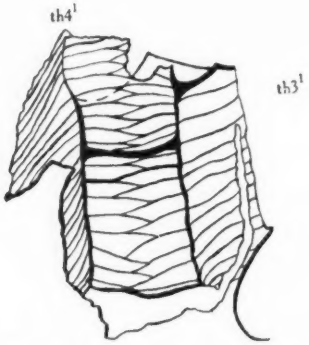
than those of later ones. This decrease is not regular, as can be seen in Text-fig. 1, but the number of growth lines does diminish from twelve in th2^1 to five in th7^1.

COMPARISON WITH OTHER SPECIES

The development as described above may be most closely compared with those of *Diplograptus gracilis* Roemer (Kraft, 1926), and *Diplograptus leptotheca* (Bulman, 1944). In all three th1^1 is formed as a U-shaped tube, and th2^1, being budded off from th1^2 at an early stage, turns outwards and upwards, filling in the space between the two limbs of th1^1. In *gracilis* and *leptotheca* the down-growing lobe of th1^2 is not so marked as here, and there the typical X-shaped pattern of growth lines is not apparent. All this is in contrast, however, to the development of forms such as *Climacograptus inuiti* Cox, which come from higher horizons, where the beginning of th1^2 occupies the crook of th1^1, and th2^1 is budded off much later, growing directly upwards.

In the latter species also the first growth rings of the metasicula form a pronounced lobe which is the beginning of the virgella, and

the thickening begins close to the prosicula ; in the others this thickening is only produced further along the metasicula. The metasicula of *inuiti* is complete before the foramen of the initial bud appears ; those of *gracilis* and *maxwelli* continue to grow concurrently with the initial bud. Thus when *inuiti* is compared with species from older rocks it is seen that the formation of the initial bud is morphologically delayed—a parallel with the late production of th2^1 (see above and Cox, 1933, p. 11).



TEXT-FIG. 9.—Drawing of part of a specimen of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. The axial wall of the rhabdosome on the reverse side is torn, thus exposing the interthecal septum of th3^1. × 75 approx. SM. A24297.

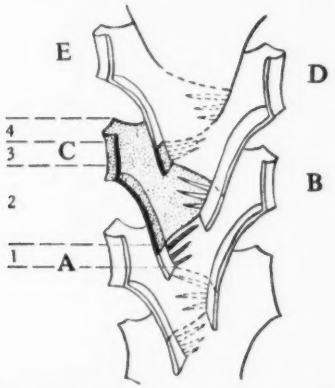
INTERTHECAL SEPTUM

Specimens at the 2^1 and 3^1 theca stages show the last-formed theca projecting above the beginning of the next (Text-fig. 7B and C). In Text-fig. 7C it can be seen that the growth lines on th3^1 are continuous from the outer wall to the interthecal septum and so the septum must be formed by the individual occupying th3^1. Where the theca is fully formed the septum appears as in Text-fig. 9 with a thickened region about 2/3 of the way along its length. Proximally the growth lines continue on to the outer wall of the theca as before, but distal to the dark region they do not. Here the chitin strips are continuous from the septum to the beginning of th4^1. Thus this thickening marks the place of change where individual 4^1 takes over formation of the septum from individual 3^1, and when the aperture of th3^1 is passed this septum becomes the ventral wall of th4^1.

This change from one theca to the next can be traced all the way up the rhabdosome, in the axial portion, by the regions of very close growth lines, where there are " unconformities " between them. It is seen that in this species the bands produced by one individual begin about half or one-third of the way below the aperture of the

previous theca on the same side, and this continues up the length of the rhabdosome, thus confirming that the condition described above is general (see Text-fig. 1).

But below this " unconformity " there are a few strips wedging out towards the opposite side, and interdigitating with complete strips belonging to the theca on the opposite side (Text-fig. 1). These are somewhat variable in number and position and it is not certain which individual formed them : whether, for example, those stippled in Text-fig. 10 were produced by B and are thus merely part of that theca,



TEXT-FIG. 10.—Diagram showing the relationships of adjacent thecae in the rhabdosome of *D.* cf. (*Amplexogr.*) *maxwelli* Decker. The letters A–E indicate successive thecae, the figures 1–4 the stages in the formation of theca C.

or whether they were in fact laid down by individual C and thus represent the earliest part of thC. In this case individual C must have been separate from B at an early stage, before B reached maturity.

If the latter is the case, the production of chitin by one individual may be divided into four stages (Text-fig. 10). Considering the one occupying thC, it forms :—

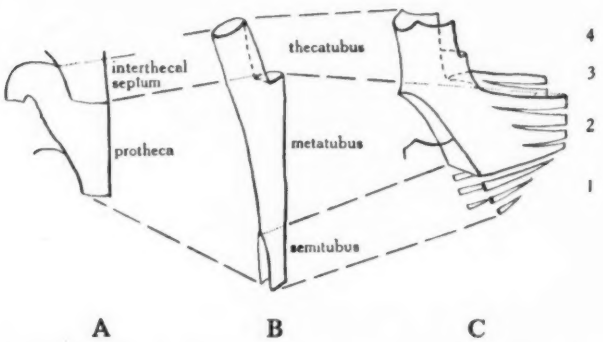
1. Short irregular wedges separate on each side of the rhabdosome, interdigitating with stage 2 of theca B, and attached at their broad ends to the dorsal wall (interthecal septum) of thA.

2. A half tube attached to the dorsal wall (interthecal septum) of thB, interrupted on the dorsal side by wedges (stage 1) of thD. It is slightly variable in that the first few chitin bands may not reach right across to the interthecal septum but join the last growth band or last few growth bands of stage 2 of the preceding theca. At first the ventral margin of this type forms the interthecal septum of thA, and then the ventral margin of thC, when the aperture of A is passed.

3. A complete tube forming the base of the interthecal septum of thC.

4. A half-tube attached to the ventral wall of thE (which is here part of the interthecal septum of thC).

In the first stage, as explained above, the chitin pieces are wedge-shaped and are deposited separately on each side of the rhabdosome. In the second and fourth stages, half tubes are formed. Here each segment consists of two strips of chitin joining with a zig-zag suture on the ventral wall. Only in the third stage does the individual produce



TEXT-FIG. 11.—Diagram comparing the parts of one thecal segment as defined A by Bulman. B by Münch. C in this paper.

complete rings with two sutures, one being found as before in the ventral wall and the other dorsally in the basal part of the interthecal septum.

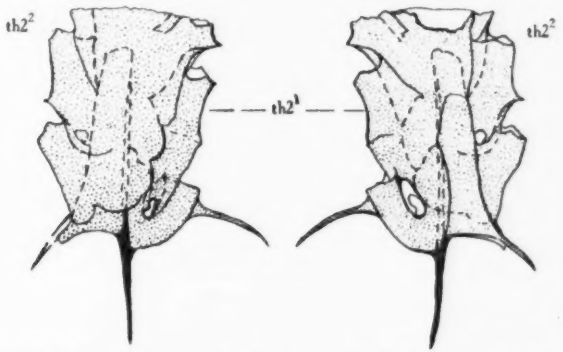
These four stages cannot be linked exactly with the terminology used by other writers, since both Münch (1938) and Bulman (1951) dealt with Monograptids and this is a diplograptid form with no median septum ; also, in the Monograptids it would seem that the interthecal septum may not be composite, as it is here. However, the diagram (Text-fig. 11) indicates such correspondence as exists : stage 1, being open ventrally, compares with the semitubus of Münch and stage 2 with his metatubus, while both these together are equivalent to the protheca of Bulman. In practice the term protheca is the most useful, since it can be applied to material in almost any state of preservation without exact knowledge of the growth lines and the way in which the interthecal septum is formed.

It may be noted that if the wedges of stage 1 are considered not to be the first expression of a new theca then they must belong to the previous one, and stage 1 of any theca becomes merged with stage 2 of the preceding theca.

Abnormalities

Among the slides prepared, a few specimens show peculiarities of growth and structure which it is thought are worth mentioning.

The first of these is a prosicula with an extremely thick chitinous wall, dark brown when cleared in comparison with the usual pale yellow. Some spiral thickening can be seen near the aperture, at about the usual spacing ; there are four full-length strengthening rods, and one short one at the apertural end. The first half-ring of the metasicula borders the margin of the aperture (SM. A 24299).



Text-fig. 12.—Outline drawing of specimen of *D.* cf. (*Amplexogr.*) *maxwelli* Decker showing abnormal development with holes (unshaded) at the base of th2¹ and th2². × 22 approx. SM. A24300.

An abnormal metasicula is seen in Text-fig. 2K, in which a distinct notch is present opposite the virgella. The usual growth lines of the metasicula are cut off by the last few, which run parallel to the margin of the notch ; it would seem that the sicula had at first taken its usual shape, and then part of the wall was either resorbed or destroyed, forming the notch. Further growth consisted of strips of chitin laid along each edge, producing an oblique margin to the aperture. This is comparable with the regeneration described by Kozlowski in some dendroids (Kozlowski, 1949, p. 159, fig. 46C).

In general the only theca bearing a spine is the first, but in one specimen (Text-fig. 6D) there is a short spine at the base of th2¹, on the obverse side. It points downwards and its production interferes little with the growth lines.

One specimen which has grown up to th3¹ shows incomplete formation of the third and fourth thecae, so that there are holes in the wall of the rhabdosome (Text-fig. 12). At the base of th2¹ there is a large gap on the obverse side and a smaller one on the reverse side. The base is not sealed off so that the inside of the theca was in communication

with the exterior here as well as at the aperture. At the base of th2[2] there is a small hole on the obverse side only ; it is not clear whether the base was open, as above, or sealed off. The margins of all the holes are thickened and the periderm is not torn. Th1[1] and 1[2] are normal in shape, but th2[1] is much elongated and th2[2] less so. Some elongation of the third theca is also seen in the specimen shown in Text-fig 7C and D.

Finally may be mentioned a number of minor " rejuvenations ", where the chitin bands show some disconformity. These are not constant from one specimen to another, and probably have little significance, perhaps indicating a slight pause in growth. They can be seen for example in Text-fig. 3F on th1[1].

ACKNOWLEDGMENTS

I should like to express my grateful thanks to Dr. O. M. B. Bulman, who has given me his help and advice throughout all this work. I am indebted also to Dr. R. H. Flower, who supplied the material ; to the Council of Girton College for the award of a Tucker-Price Studentship, and to the Department of Scientific and Industrial Research for an award, during the tenure of which the work has been carried out.

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The Stratigraphy of Cuilcagh, Ireland

By Peter Padget

Abstract

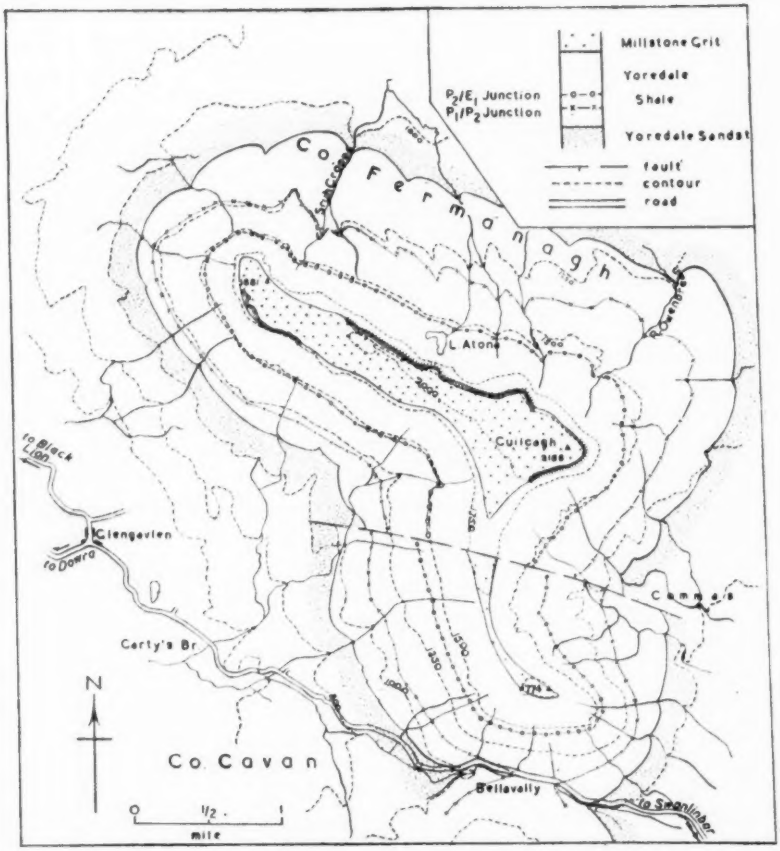
Of the three main lithological units on Cuilcagh, namely, Millstone Grit, Yoredale Sandstone, and Yoredale Shale, particular attention is paid to the latter which attains a thickness of 700 feet. Numerous goniatites were collected from the lowermost 450 feet of it and these establish the existence of the P_{1b}, P_{1c}, P_2, E_{1a} zones and possibly the E_{1c} zone also. Higher beds are very poorly fossiliferous and their age is uncertain. Brief comparisons are also made with Yoredale Beds in England and in other parts of Ireland.

Introduction

CUILCAGH, or Cuilcagh Mountains to be more exact, is the name given to an elevated region in the north-west of Ireland on the borders of Counties Fermanagh and Cavan. When seen from the north it is distinctly flat-topped with fairly steep sides merging downwards into more irregular ground around the 1,000 foot contour. It consists of two prominent spurs which radiate from the highest point (2,188 feet), one to the north-west, the other to the south, with a concavity to the east (see Text-fig. 1). Three main lithological units are present. These are, the Yoredale Sandstone which overlies a thick mass of Carboniferous (Avonian) Limestone, the Yoredale Shale, and the Millstone Grit, each of which can be distinguished and mapped without difficulty. The Grit, for example, caps the highest ground and overlies the softer and more easily eroded Yoredale Shale. The latter makes up most of the bulk of the mountain, outcropping on the steeper slopes and resting on a platform of Yoredale Sandstone.

Wherever observed the beds are horizontal or gently dipping. Mapping, however, reveals a small regional dip to the west. No major faults disturb the beds though one displacement with a throw of 100–150 feet became apparent after mapping the faunal and lithological horizons and its inferred position is shown on the accompanying map.

The lithological and topographical resemblances to mountains of similar age in the north of England were appreciated at an early date. Phillips, for example, who was very familiar with the geology of Yorkshire and also paid visits to Fermanagh and other parts of Ireland, wrote of Cuilcagh (or Kulkeagh as he and other early workers called it): " . . . while the forms of Ben Jochlin, Kulkeagh, and Belmore seemed copied from Penyghent, Wild Boar Fell, and Water Crag, their constituent rocks were found to be closely analogous" (1836, p. xv). A better comparison might have been made with Pendle Hill, Lancashire, which Cuilcagh resembles not only in its topography and lithology but also in the fauna of its shales.



TEXT-FIG. 1.—Geological Map of Cuilcagh Mountain, Ireland.

The resemblance to the land forms and geology of the north of England was further emphasized when lithological names such as Millstone Grit were formally adopted in the official geological survey for beds of similar type and age in Ireland.

In the present paper attention is drawn to the fauna of the Yoredale Shale of Cuilcagh which resembles that of the Bowland Shale of Yorkshire and Lancashire. By means of the goniatites it has been possible to establish the existence of the faunal stages P_1, P_2, and E_1, thus enabling the older lithological units to be correlated with other successions in Ireland and England.

Few of the streams draining Cuilcagh have names, so for convenience of description it is proposed to group them into three series,

namely, those on the north-east facing slopes (Co. Fermanagh side), those on the east-facing slopes (Commas side), and those flowing south and west (Glengavlen side).

I should like to take this opportunity of thanking Mr. W. S. Bisat and Mr. E. W. J. Moore for their ready help with the identification of the goniatites and for much helpful discussion ; Mr. J. S. Turner who has shown a constant interest in the progress of the work ; and Professor T. N. George and Dr. E. D. Currie for reading through and commenting on the final script.

Lithological Details

The *Yoredale Sandstone*, 300 to 400 feet thick, which overlies the Upper Limestone, is largely obscured by drift and peat but forms a distinct feature in the general relief. Numerous exposures of it occur in streams, however, where the beds often form small waterfalls. On the Co. Fermanagh side, these usually consist of massively bedded sandstones and grits but in one stream about 20 feet of calcareous shales and mudstones are apparently interbedded though the field evidence is not conclusive on this point. Fossils collected from the shale include *Allotropiophyllum tuberculatum* (Thomson), *Cryptophyllum enorme* Hudson, *C.* cf. *hibernicum* Carr., *Tryplophyllites* of the *enniskilleni* group, *Euphemites* sp. : no goniatites were found.

The junction between the sandstone and the Yoredale Shale is a sharp one.

On the Glengavlen side, the sandstone is less marked as a feature of the relief and this may be due to the presence of numerous bands of silty, micaceous, and unfossiliferous shales which allow more rapid denudation.

The *Yoredale Shale* attains a thickness of about 700 feet on the east-facing slopes and this is apparently maintained all around Cuilcagh. Exposures are often remarkably good where fast-flowing streams have carved deep gullies in the relatively soft shale, especially when superficial deposits are thin or absent. Often, however, large blocks of the overlying, massively bedded Millstone Grit have slipped down and now obscure the shale outcrops while the stream courses also are hidden from view for considerable distances. This is particularly noticeable on the south-west slopes of the Glengavlen side. Nowhere has a continuous succession been found from the base to the top of the shale though the upper course of the stream known as the Sruh Croppa on the Co. Fermanagh side offers a nearly complete section of the fossiliferous part of the shale.

In spite of these adverse factors it is possible to distinguish lithological variations in the shale which persist laterally at the same horizon around the mountain.

The lowermost 100 feet of beds are calcareous shales. About 20 feet above the base, hard bands of calcareous mudstone are interbedded and some of these weather to a distinctive brown colour. Like the shales they are fairly fossiliferous and have yielded numerous goniatites. The succeeding 50 feet of shales are somewhat ferruginous and contain pyrites which has partially replaced some of the fossils. A few hard bands of mudstone are also present but these do not weather to a brown colour. Higher shales, 50 feet or so in thickness, are more calcareous, but hard bands of mudstone, slightly pyritic and weathering to a pale buff colour, are interbedded with them. Above this, the beds are unfossiliferous through the next 100 feet or so of flaky, micaceous, slightly ferruginous shales which also contain numerous mudstone pellets.

Then quite abruptly, harder shales, weathering brown appear. The first 30 to 40 feet of these contain abundant crushed specimens of goniatites and lamellibranchs ; they pass upwards into fossiliferous strata with bands of sideritic ironstone. The highest beds are well exposed in the steep, east-facing slopes on the Commas side where, in a cliff 70 feet high, the uppermost 35 to 40 feet consist of interbedded micaceous shale, sandstones, and siltstones, devoid of any fossil remains other than a few worm tracks. At a comparable horizon on the Co. Fermanagh side some moulds left by crinoid ossicles were found.

The *Millstone Grit* crops out on the highest ground, where it sometimes forms a " pavement " traversed by joints. Here and elsewhere it is massively bedded grit with impersistent lenses of pebbles. Along the margins, large blocks have broken away and now rest some distance downhill on the underlying shales. No fossils were found, but the Survey geologists recorded plant remains from the basal beds (Wilkinson and Cruise, 1886, p. 19).

Faunal Stratigraphy of the Yoredale Shale

It has long been known that goniatites occur in the Yoredale Shale of Cuilcagh. Phillips recorded (1836, pp. 234. 236, 237), for example, various species including *Goniatites striolatus*, *G. rotiformis*, and *G. calyx*. At a later date, the Geological Survey (Wilkinson and Cruise, 1886, p. 19) recorded *G. sphaericum* var. *crenistriatus* and *G. striolatus* in some abundance from exposures on the Commas side. No recent work has been carried out in the area though Moore (1936, pp. 395–6) re-identified Phillips' *G. calyx* as a species of *Girtyoceras* and *G. striolatus* as a species of *Sudeticeras*.

In the present investigation new collections of goniatites were made from the Yoredale Shale and the faunal horizons traced round the slopes of Cuilcagh. These indicate the existence of the P_1, P_2,

and E_1 stages. Some of the species and species-groups present enable the zones within each stage to be identified. A number of apparently undescribed forms are present, and when taken in conjunction with known species allow a fairly refined subdivision of the lower part of the shale to be made on the lines of that carried out for similar beds in England such as Pendle Hill, Lancashire (Moore, 1936).

(i) *Lower Bollandian*, P_1

P_{1b}

The lowermost 50 feet or so of the Yoredale Shale yield abundant goniatites. From the lowest fossiliferous horizon only 8 feet from the base of the shale and on the Glengavlen side of Cuilcagh, forms were found closely resembling *G. falcatus* from Cowdale Clough, Lancashire, in their suture-lines. One specimen of *Pronorites cyclolobus* (Phillips) was also found in association with them.

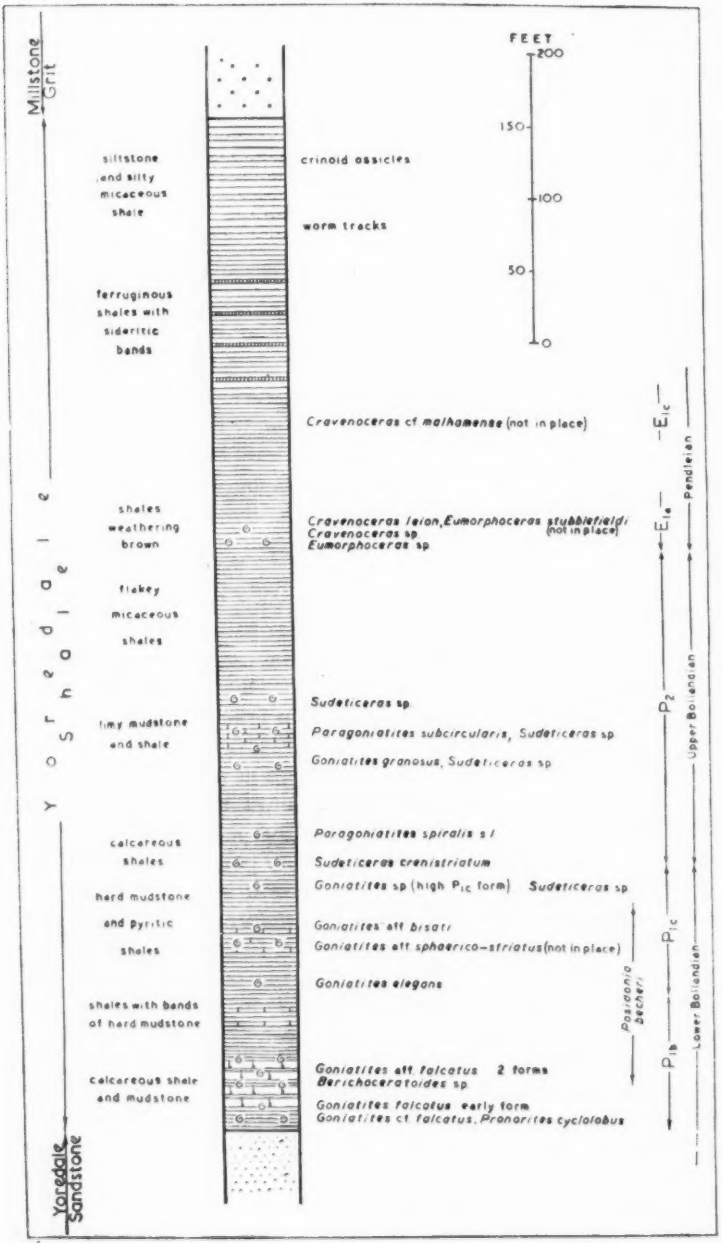
On the Co. Fermanagh side, shale impressions of *G. falcatus* (early form) showing the highly characteristic, falciform ornament were found at a low horizon in the shale. In the Survey Museum, London, one specimen (No. 5857) from the " Upper Shale, Kulkeagh " has been identified as *G. falcatus* Roemer.

The most richly fossiliferous beds, however, occur from 20 to 50 feet above the base of the shale. These have yielded a number of specimens of which the most abundant is a form having a shape and suture-line closely similar to *G. falcatus*. Only occasionally can the ornament be seen to consist of fine, spiral lirae on the venter though one specimen showed a tiny patch of crenistriate transversals on the flank. These are referred to *G.* aff. *falcatus* as are a small number of stouter and more widely umbilicated forms associated with them. The latter show slight differences from true *falcatus* in their suture-line, the saddles being straighter and more pointed. They are intermediate in this respect between *G. falcatus* and *G. elegans*. One further specimen referred to *Beyrichoceratoides* sp. was found at this horizon and is identical with specimen No. 5869 in the Survey Collection which Mr. W. S. Bisat also identified as belonging to this genus. Both specimens have suture-lines similar to *B. implicatum* except that their lateral lobes are relatively wider.

The evidence then indicates that the basal beds of the Yoredale Shale belong everywhere to the P_{1b} zone. There is no evidence to prove the existence of the underlying P_{1a} zone but it is possible, of course, that the Yoredale Sandstone may be, in part at least, of this age.

P_{1c}

The shales and mudstones of the P_{1b} zone are succeeded by less calcareous beds with a fauna characteristic of the P_{1c} zone. Solid



TEXT-FIG. 2.—Vertical Section of the Yoredale Shale, Cuilcagh.

goniatites are much less common though a few good pyritized specimens were collected.

In the Sruh Croppa stream and about 100 to 120 feet above the base of the shale, partly crushed specimens were found having the ornament typical of *G. elegans*. Higher shales yielded somewhat pyritized forms with crushed outer whorls and uncrushed interiors identified as *G.* aff. *bisati* Moore. The same bed also contains partially crushed forms whose ornament resembled that of *G. bisati* also. A single specimen of *G.* aff. *sphaerico-striatus* was found loose at a slightly lower elevation. The uppermost beds of the zone also yielded a specimen having a suture-line characteristic of the genus *Sudeticeras*. Elsewhere in the area a number of solid forms, also slightly pyritized, were collected from the upper beds of the P_{1c} zone. The saddles in their suture-lines are intermediate in shape between those characteristic of the two genera *Goniatites* and *Sudeticeras* as defined by Moore (1950, p. 32). The same bed also contains crushed goniatites displaying good spiral ornament and often transversals which are bowed forward to form a prominent latero-ventral salient.

Few species near the P_1/P_2 junction have been described from the main collecting areas in England such as Pendle Hill, Lancashire, owing to the unsatisfactory nature of the exposures there at this horizon. It seems likely, therefore, that the new and undescribed species collected on Cuilcagh may go some way towards closing this gap in our knowledge and lead to the recognition of a P_{1d} zone as has been done on the continent. It is felt, however, that the material to hand is not yet adequate enough to permit the necessary new species to be described from it.

The non-goniatitic fauna of the P_1 stage includes numerous lamellibranchs of which the most abundant is *Posidonia becheri*. Many brachiopods are also present (*Martinia* sp., *Productus* spp.), gastropods (*Euomphalus* sp., *Glabrocingulum* sp.), orthoconic Nautiloids, and a few solitary corals (*Fasciculophyllum* sp., *Rylstonia* sp.).

(ii) *Upper Bollandian, P_2*

In the upper part of the Sruh Croppa stream limy shales containing *Sudeticeras crenistriatum* (Bisat) overlie the P_{1c} zone conformably and the occurrence of this species is taken to indicate the base of the Upper Bollandian.

The next 30 feet of beds immediately above *crenistriatum* are poorly exposed in this stream but elsewhere on Cuilcagh good specimens of *Goniatites granosus* and *Paragoniatites subcircularis* displaying the ornament characteristic of each were collected from exposures of shale at this horizon and a little higher. The two species were never found together and their relationship to each other in the succession is

uncertain though *granosus* appears to underlie *subcircularis* and also to lie closer to the base of P_2. A few specimens associated with *subcircularis* show good spirals which are intermediate in density between *granosus* and *subcircularis* at comparable diameters and are referred to *P. spiralis* s.l.

In addition to the above a number of crushed specimens of *Sudeticeras* were found. These occur most prolifically in a band of shale 2 feet thick and about 25 feet above some limy mudstones containing *P. subcircularis*, *Leiorhynchus* sp., and *Orbiculoidea* sp. No solid specimens of *Sudeticeras* were found, however, but all have strongly developed transversals which are smooth on the lateral slopes but crenistriate on the latero-ventral shoulder and venter. Faint spirals were also just discernible on the venter of one specimen. The transversals also turn forward on leaving the umbilicus, forming a strong lingua and then reflexing over the venter to form a deep hyponomic sinus : these features are particularly well seen close to the apertural margin of one specimen.

Another form, from some beds about 12 feet above a shale yielding *subcircularis* on the Commas side, shows stronger crenistriation of the transversals on the flanks but these give way to equally strong spirals on the latero-ventral shoulder and venter.

A third form of *Sudeticeras* with less sinuous transversals radiating from the umbilicus and strong spiral ornament is found in association with *subcircularis* and *granosus*.

Included also in the P_2 stage are about 100 feet of unfossiliferous micaceous shales. These lie between the horizon with the specimens of *Sudeticeras* discussed above but underlie the next faunal horizon which is of early E_1 age.

(iii) *Pendleian*, E_1

The base of the Pendleian is taken at a distinctive horizon of shale which weathers brown and contains many crushed fossils including *Eumorphoceras* sp. and *Posidoniella laevis* (Brown). These are particularly abundant through 30 feet or so of beds but become less numerous upwards and eventually disappear altogether. Above them, some crushed goniatites, probably *Cravenoceras*, were found in one stream section on the Glengavlen side.

The specific identity of the *Eumorphoceras* sp. is difficult to decide owing to the crushed state of the specimens but it appears to have a fairly small umbilicus with a distinct umbilical edge : the ornament consists of radiating riblets which are sometimes visible on the very early whorls. The latero-ventral groove is usually conspicuous but varies in strength from one specimen to another and there is also a vague suggestion of a latero-ventral salient on some specimens.

These features suggest a comparison with forms like *Eumorphoceras* sp. *A* as described by Moore (1946, p. 418) rather than with any other species and would indicate a low horizon in E_1 (Bisat, 1950, p. 24). Bisat has, however, pointed out the difficulty of identifying some of these forms of *Eumorphoceras* from shale impressions alone and further speculation on the form from Cuilcagh seems unwarranted.

On the north-western extremity of Cuilcagh some loose fallen blocks of a hard limestone were found resting on *Eumorphoceras* shale : this yielded numerous uncrushed specimens of *Cravenoceras leion* Bisat and a lesser number of *Eumorphoceras stubblefieldi* Moore. Such species indicate a low horizon in the E_1 stage and probably low in E_{1a}. *C. leion*, however, as pointed out by Bisat (1950, p. 21), is known to have a range of 20 to 30 feet in England and in itself does not necessarily indicate the very base of the Pendleian. He also suggested (loc. cit., p. 24) that *E. stubblefieldi* belongs to a faunal horizon a little above the base of the Pendlian. The fossils from the limestone blocks, therefore, probably denote a horizon a little above the base of the Pendleian also and above the shales with *Eumorphoceras*.

No higher goniatite-bearing horizons were found in the Yoredale Shale but some loose blocks of ferruginous shales yielded partially crushed specimens of *Cravenoceras* cf. *malhamense* (Bisat). These would indicate the existence of the higher E_{1c} zone.

No trace of any of the diagnostic fossils of the E_2 stage was found in the area and the precise age of the higher shales and siltstones and of the Millstone Grit is not known.

Comparison with other Areas

The fauna of the Yoredale Shale shows strong similarities to that of the Bowland Shales of the north of England. The Yoredales of England, on the other hand, are usually poor in goniatites and show evidence of rhythmic deposition (Hudson, 1926, p. 125) so that the use of the term " Yoredale " for the sandstone and shale of Cuilcagh is somewhat ill-chosen. The term, however, is now fairly entrenched in the literature.

Yoredale Beds elsewhere in Ireland sometimes contain good faunas though little up-to-date work has been published on them. In east Tyrone they apparently begin in the D_2 zone and end at the top of P_2 or E_1 (Hartley, 1945, p. 257), and are thus comparable in age with the Yoredale Shale of Cuilcagh. In south Tyrone, the author's own work shows that the " Yoredale Beds " there are more variegated lithologically. Goniatites of B_2 and P_1 age occur in the lower part but higher micaceous shales and siltstones are unfossiliferous and their age is consequently uncertain.

It is also interesting to note that the marked non-sequence which

exists between the Viséan and Namurian further south in Ireland, in Co. Dublin for example (Smyth, 1950, p. 303), is absent from the shales of Cuilcagh.

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The Diorites and Associated Rocks of the Glen Tilt Complex

III. Hornblende-Schist and Hornblendite Xenoliths in the Granite and Diorite

By W. A. Deer

Abstract

The diorites and Sron a' Chro' granite of the Glen Tilt complex enclose hornblende-schist xenoliths derived from the Dalradian epidiorites of the country rock. Small hornblendite xeoliths are found in the complex but are restricted to the diorite outcrop. Porphyroblastic hornblende is developed within the schist xenoliths and reaction zones rich in hornblende are formed around the xenoliths. The mineralogical and textural characteristics of these reaction products suggest that the typical two-hornblende generation appinites of the complex represent modified hornblende schist. A similar origin for the quartz-orthoclase-appinite of the complex is rejected and their development from hornblendite is indicated.

1. Introduction

ALONG the south-western margin of the Glen Tilt intrusion (Deer, 1938) a number of epidiorite bands of the Dalradian series come into contact with the Sron a' Chro' granite and the diorites of the main intrusion. Xenoliths of these hornblende schists are found in the diorites and granite and, both as xenoliths and as country rock adjacent to the intrusion, often develop a marginal zone rich in hornblende. The Sron a' Chro' granite encloses many large hornblende schist xenoliths in which the development of hornblende porphyroblasts at the contacts and along planes of injection may be observed. No large but many small inclusions of hornblende-schist are found in the diorites which also encloses small hornblendite xenoliths.

2. Hornblende-schist Xenoliths

Large schist xenoliths in the granite may be seen in the Allt Craoinidh, half a mile from its junction with the Tilt, and many smaller xenoliths are found above Clachghlas and in the stream a quarter of a mile to the north-east. Except for the marginal development of large crystals of hornblende the xenoliths are typical of the Dalradian epidiorites. In hand specimen their texture is medium to fine-grained and the rock consists essentially of hornblende and plagioclase. In thin section a little quartz, orthoclase, sphene, apatite, magnetite, and zircon occur as accessories and epidote is sometimes present in thin attenuated veins. The composition of the unaltered hornblende schist falls within the range of normal Dalradian epidiorites (Table 1). The green hornblende of this rock has been analysed (Deer, 1938, and Table 2). Compared with the diorite and appinite horn-

TABLE 1.—ANALYSIS OF HORNBLENDE SCHIST

	1.	A.	B.
SiO_2	48·82	48·20	52·35
Al_2O_3	15·47	14·40	14·80
Fe_2O_3	3·79	0·69	1·64
FeO	6·85	8·32	9·12
MgO	9·48	12·75	6·50
CaO	10·17	8·40	9·30
Na_2O	2·19	1·59	2·10
K_2O	0·91	0·24	tr.
H_2O+	0·59	3·80	2·50
H_2O-	0·14	0·40	0·15
TiO_2	1·25	0·90	1·20
P_2O_5	0·20	0·08	tr.
MnO	0·28	0·25	0·25
	100·14	100·02	99·91

Norm.		*Mode.*	
Orthoclase	5·56	Quartz	0·9
Albite	18·34	Plagioclase	37·6
Anorthite	29·75	Hornblende	57·6
Diopside	15·79	Accessories	3·9
Hypersthene	15·76		
Olivine	6·18		
Ilmenite	2·43		
Magnetite	4·87		
Apatite	0·34		

1. Hornblende schist ; centre of large xenolith, Allt Craoinidh, 1,000 yards from junction with the Tilt. (Anal. W. A. Deer.)

A. Chlorite-clinozoisite-albite-amphibolite. (Wiseman, 1934, p. 372.)

B. Chlorite-epidote-albite-amphibolite. (Wiseman, 1934, p. 368.)

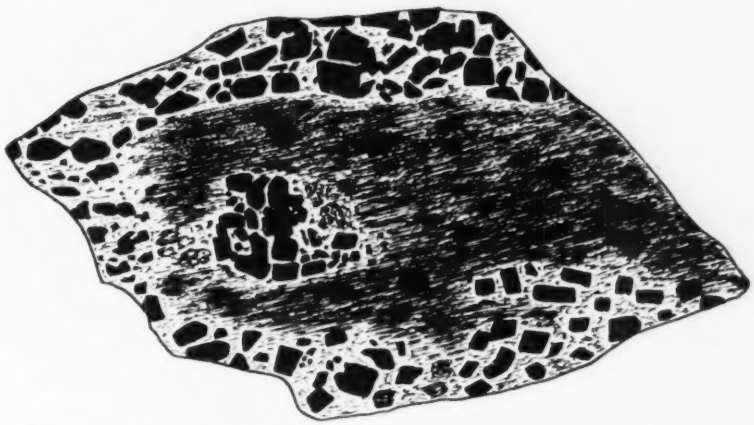
TABLE 2.—HORNBLENDE ANALYSES

	1.	2.	3.	4.	5.	6.
SiO_2	44·23	44·15	47·14	48·32	48·96	42·80
Al_2O_3	14·62	10·59	9·44	6·43	7·85	10·55
TiO_2	1·81	3·73	1·74	1·43	1·07	1·62
Fe_2O_3	5·11	5·02	3·66	5·45	3·62	6·62
FeO	8·94	8·89	8·38	7·90	8·25	9·16
MnO	0·21	0·17	0·11	0·13	0·12	0·24
MgO	10·78	12·30	14·44	14·82	15·69	12·48
CaO	10·81	11·80	10·53	11·99	11·90	11·67
Na_2O	1·51	1·26	1·15	0·99	1·04	1·89
K_2O	0·61	1·10	1·30	0·67	0·53	1·00
H_2O+	1·42	0·95	2·00	1·61	0·63	1·73
H_2O-	0·08	0·11	0·53	0·06	0·08	—
F	0·22	0·84	—	tr.	1·41	—
P_2O_5	—	—	—	—	—	0·24
	100·35	100·91	100·42	99·80	101·15	100·00
Less O for F	0·09	0·36	—	—	0·61	—
	100·26	100·55	100·42	99·80	100·54	100·00
γ	1·677	1·673	1·669	1·671	1·670	—

1. Green hornblende, hornblende schist.
2. Porphyroblastic brown hornblende, injected hornblende schist.
3. Brown hornblende developed marginally around hornblende-schist xenolith in quartz diorite.
4. Greenish-brown hornblende, quartz-orthoclase appinite.
5. Brownish-green hornblende, hornblendite xenolith.
6. Average hornblendite (Daly, 1935).

blendes it is richer in alumina and poorer in magnesia and, as Wiseman (1934) has shown, these characteristics are related to the high metamorphic grade of the schists.

Injected hornblende schists are also exposed just above the junction of the Allt Coire Duhb Bhaid with the Allt a Chama Choire. Here, the development of stringers of acid plagioclase and potash feldspar within the schists is accompanied by the crystallization of large porphyroblastic hornblendes (Text-fig. 1). These later-formed horn-

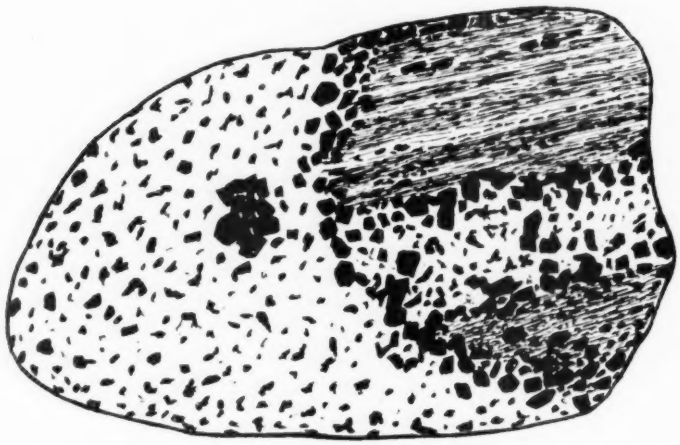


TEXT-FIG. 1.—Hornblende schist xenolith showing the crystallization of incipient hornblende porphyroblasts within the body of the schist and well-developed crystals along schistosity planes. Scale 2/3 natural size.

blendes are developed most frequently along the planes of schistosity but the recrystallization also occurs in irregular patches within the schist. During the earlier stages of their formation the hornblendes are pale brown in colour and enclose many small crystals of the original green variety and the recrystallization is not associated with any mechanical addition from the granite. Close to the stringers of potash feldspar and acid plagioclase the hornblende of the schist xenoliths increases in grain size until all included material is either absorbed into the composition of the newly-constituted amphibole or is ejected beyond the crystal margins. This hornblende (Table 2, No. 2) is deep brown in colour and the main chemical changes associated with the conversion of the green hornblende of the schist to the brown hornblende adjacent to the acid stringers are an increase in magnesia and a decrease in alumina. Finally, where the feldspathic stringers are conspicuously developed, the large brown hornblende become separated from the original body of the schist and are enclosed in a finer-grained matrix of acid plagioclase and potash feldspar. At this stage a second

hornblende crystallizes. This hornblende is green in colour, of equivalent grain size to the feldspars and, optically, compares closely with the second hornblende generation of the typical appinites.

The small hornblende-schist xenoliths enclosed within the diorite show a similar development of porphyroblastic hornblende. In the specimen figured (Text-fig. 2) the xenolith has a typical schistose texture with elongated sieved crystals of pale green hornblende, some of which show a little patchy alteration to a brown variety. The plagioclase,



TEXT-FIG. 2.—Hornblende schist xenolith in quartz diorite. Scale 7/8 natural size.

an oligoclase-andesine, occurs in small laths with regular albite twinning. Towards the contact with the diorite the hornblendes of the schist xenoliths rapidly increase in size and the original green variety is almost completely replaced by a brown hornblende. Crystallization of the brown hornblende also occurs along the laminae of the schist. The transformation of the green to the brown hornblende is restricted to a narrow zone, both around the periphery of the xenoliths and along the margins of the injecting veins of diorite. Compared with the original mineral of the hornblende-schist the composition of the reconstructed hornblende shows a marked decrease in alumina and corresponding increase in magnesia. Some of the newly-formed hornblendes, close to but separated from the reaction borders of the xenolith, have a narrow margin of green hornblende but, apart from this marginal modification, undergo no further change. The composition of this mineral is intermediate between the large phenocrystal and the smaller, second-generation hornblendes of the appinites (Deer, 1950). The failure to approach more closely the composition of the

second-generation hornblendes of the appinites may be due to the development of the thin marginal zone of different composition which prevents more extensive transformation, or marks the suppression of further reaction due to the complete crystallization of the surrounding magma. Compared with the hornblende-schist the reaction zone is richer in hornblende and poorer in plagioclase. Sphene is more abundant than in the schist and is probably due to the fixation of the titania in the dioritic magma surrounding the xenoliths.

The composition of the reaction zone surrounding the hornblende-schist xenoliths has been calculated from a modal analysis; the xenoliths, rather than the injected hornblende-schists, were chosen because of the greater difficulty in obtaining a reliable modal composition for the latter. As the reaction zone consists of nearly 70 per cent of an analysed hornblende and 20 per cent plagioclase, the composition of which has been determined from its optical properties, the computed analysis cannot be very different from the true composition. This estimated composition of the "reaction zone" is very close to that of the typical appinite of the Glen Tilt complex (Table 3).

TABLE 3.—COMPOSITION OF THE REACTION ZONE

	1.	2.	3.
SiO_2	48·82	50·5	50·41
Al_2O_3	15·47	11·7	12·42
Fe_2O_3	3·79	4·1	2·54
FeO	6·85	6·4	7·12
MgO	9·48	10·0	10·22
CaO	10·17	9·9	11·76
Na_2O	2·19	2·2	2·12
K_2O	0·91	0·9	1·11
H_2O+	0·59	1·4	0·51
H_2O-	0·14	0·4	0·28
TiO_2	1·25	2·4	1·35
P_2O_5	0·20	nil	0·28
MnO	0·28	0·1	0·05
	100·14	100·0	100·17

Modes (Weight per cent).

	1.	2.	3.	4.
Quartz	0·9	5·9	6·6	15·6
Orthoclase	—	—	2·6	—
Plagioclase	37·6	20·3	26·2	58·3
Hornblende	57·6	69·9	61·6	23·0[2]
Accessories	3·9	3·9[1]	3·0	3·1

[1] Includes a few grains of clinopyroxene.
[2] Hornblende plus biotite.

1. Hornblende schist (Table 1).
2. "Reaction Zone," calculated from mode.
3. Appinite, Allt Clachaig, 1,500 feet above the Tilt (Deer, 1950).
4. Quartz diorite.

The optical properties and chemical composition of the larger hornblende porphyroblasts developed in the injected schist xenolith of the Sron a' Chro' granite and the marginally-formed hornblende of the schist xenoliths enclosed in the diorite show a well-defined

trend towards the composition and properties of the second generation hornblendes of the appinites. This progressive change is accompanied by an appreciable difference in the grain size of the minerals and corresponds to the environment in which the minerals developed. The crystallization of the large porphyroblastic hornblendes is controlled largely by the diffusion of the constituent ions in an essentially solid environment and the crystals grow by accretion as in the metamorphic rocks. Metasomatic transfer has undoubtedly taken place, as evidenced by the titanium content of the porphyroblasts. It is also apparent, from a consideration of the magnesium content of the original schist hornblende and the reconstituted brown hornblende, and of the amounts in which they are present in the xenoliths and their reaction products, that magnesium also has been introduced. It is clear that new centres of crystallization are not formed under these conditions and the growth of a small number of large porphyroblastic crystals is facilitated by the enclosure of the original smaller amphiboles of the schist xenoliths. Where the hornblendes have developed around the margins of the small hornblende schist xenoliths the environment is essentially magmatic and the hornblende individuals act as foci for the crystallization of a phase with which the magma is saturated. The restriction on the development of new centres under such conditions of crystallization is less marked, the number of centres competing for the available ions is greater and the grain size is, in consequence, smaller. This process, but to a lesser degree, also takes place within the schist xenoliths in proximity to the acid stringers.

3. Hornblendite Xenoliths

Large masses of hornblendite or pyroxenite have not been found in the complex, but small hornblendite xenoliths, rarely greater than ten inches in length, occur sporadically in the diorites. Pyroxene cores are not present in the hornblende. Apart from subordinate quartz the xenoliths consist of a brownish-green hornblende (Table 2, No. 5), the composition of which is close to those of the hornblende of the quartz-orthoclase-appinite, the small green hornblende of the typical appinites and the hornblende developed marginal around the schist xenoliths in the diorite. Feldspar is absent except marginally, where it appears to have been derived from the surrounding diorite. A hornblende-xenolith has been analysed (Table 4, No. 1) and its composition is comparable with that of the quartz-orthoclase appinite except that the latter is richer in alkalis. Most hornblendites are low in silica and compare closely in composition with both the early-formed phenocrystal hornblende of the appinites and the brown hornblende of the injected schists. Whether the hornblende of these xenoliths is secondary as in the davainites (Wyllie & Scott, 1913) or

TABLE 4.—ANALYSIS OF HORNBLENDITE

	1.	A.	B.	*Norm.*		*Mode.*	
SiO_2	55·59	43·53	42·80	Qz	10·80	Quartz	12·8
Al_2O_3	6·84	7·24	10·55	Or	2·78	Plagioclase	0·9
Fe_2O_3	3·15	11·10	6·62	Ab	7·86	Hornblende	86·3
FeO	7·17	8·70	9·16	An	13·07		
MgO	13·65	11·51	12·48	Di	27·21		
CaO	10·35	10·19	11·67	Hy	30·14		
Na_2O	0·91	2·88	1·89	Il	1·98		
K_2O	0·46	1·39	1·00	Mg	4·64		
H_2O+	0·55	1·34	1·73	F	1·21		
H_2O-	0·08	0·43					
TiO_2	0·98	1·90	1·62				
P_2O_5	0·04	—	0·24				
MnO	0·10	tr.	0·24				
F	1·22	—	—				
	101·09	100·21	100·00				
Less O for F	0·53						
	100·56						

1. Hornblendite xenolith, crags of the Stac Crom. (Anal. W. A. Deer).
A. "Davainite," Garabal Hill (Wyllie and Scott, 1913).
B. Average hornblendite (Daly, 1935).

originally an early accumulative amphibole (Nockolds, 1941), there is thus little doubt that it has been subsequently modified.

4. THE ORIGIN OF THE APPINITES

The textural and mineralogical characteristics of the injected schist and the reaction zone around the schist xenoliths leaves little doubt that the patches of typical appinite have their origin in the epidiorites of the country rock. The initial stage, the crystallization of the large porphyroblastic brown hornblende, is considered to be one of metasomatic interchange between xenolith and enclosing magma. This process was succeeded later by the invasion of magma of acid to intermediate composition from which the second-generation hornblende crystallized.

This process gives a reasonably satisfactory mode of formation for the typical appinites containing two generations of hornblendes. In the earlier paper (Deer, 1950), xenolithic masses which lack the characteristic two-hornblende generations, the quartz-orthoclase-appinites, were described and the origin of this rock requires further consideration. Two possible lines of development are suggested. The second-generation hornblende of the typical appinites crystallized in a magmatic environment and there is little doubt that its composition approaches equilibirum with the liquid in which it crystallized and that, in consequence, it represents a more stable composition

than that of the porphyroblastic hornblende. The latter crystallized as a result of metasomatic interchange between xenolith and surrounding magma and only during the latest stages of the appinite formation did this mineral enter a magmatic environment, a stage which is represented by a very narrow rim having the same optical properties of the second-generation hornblende. Complete transformation of the porphyroblastic hornblende to the composition of the second-generation hornblende must be assumed if the derivation of the quartz-orthoclase appinites from modified schist is accepted. Although rocks which are difficult to classify as either typical two-generation or single-generation hornblende appinites are occasionally found within the diorite outcrop (Deer, 1950), the assumption that such rocks represent a gradual transition from one type to the other is unsound. In all these intermediate types the hornblende is neither uniform in composition nor in grain size.

The second alternative, i.e. the formation of the quartz-orthoclase appinite by the chemical transformation of a rock different in composition from the epidiorites from which the hornblende-schist xenoliths were derived, is more attractive. The only other rock within the complex which is likely to form the starting point of such a transformation is hornblendite. No support for this line of development was obtained in the field but the absence of hornblendite xenoliths associated with the quartz-orthoclase appinites may be due to lack of exposures in the area where these appinites are developed. It has, however, been shown earlier that on general grounds it is reasonable to consider that the original hornblendite mineral has been extensively reconstituted and, further, that the hornblendes of the quartz-orthoclase appinite and the hornblendite-xenoliths possess marked similarities of optical properties and chemical composition. Moreover, the hornblende of the hornblendite is uniform in composition and grain size. The absence of porphyroblastic crystallization in the quartz-orthoclase-appinite thus appears to be related to the original monomineralic composition of the hornblendite in which the transformation took place crystal by crystal. This original textural characteristic does not, however, explain the more complete transformation of the hornblende compared with the porphyroblastic hornblende developed in modified schist xenoliths. Thus, in addition to the difference in original composition of the two rocks, another factor must have been operative. Hornblendite does not occur as country rock and its origin can only be referred to that of cognate xenoliths in contrast with the accidental nature of the inclusions of hornblende-schist, and the consequence, a longer reaction-period and more extensive transformation. Evidence of this factor is shown by the uniform mineral composition already attained by the hornblendite xenoliths

prior to their incorporation in the surrounding magma and modification to form rocks of appinitic character.

Although it is not possible to show by direct observation that the two varieties of appinite have developed along the lines described, the evidence of their variation in mineralogical composition and textural characteristics gives a considerable degree of support to the thesis that the typical two-hornblende generation appinite and the single-hornblende generation appinite represent in the first case modified hornblendite-schist and in the second hornblendite. There is no evidence that either the typical appinite or the quartz-orthoclase appinite have been formed by a process of pure crystallization differentiation or one involving crystal accumulation.

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Seven New Genera of Jurassic Ammonites

By W. J. Arkell

(PLATE I)

Abstract

Well-defined genera of ammonites from the Toarcian, Bathonian, Oxfordian, Kimeridgian, and Tithonian are diagnosed and named.

Introduction

In the international *Treatise on Invertebrate Paleontology* an attempt is being made to assemble diagnoses and figures of all known genera and subgenera, and it is hoped that the text may remain useful as a work of reference for many years, as complete as its authors can make it.

In the sphere of ammonites, at least, the naming of genera has been fortuitous and extremely uneven, depending largely on where two or three authors who employed a refined taxonomic scale have chanced to work. For such families or formations we have a host of generic names, largely bestowed on figures previously published by other authors. Anyone who attempts to assemble the names becomes aware of the existence of other figured forms, equally or more deserving of generic separation, which will certainly be named as soon as a worker takes up the group concerned. Since no new genera are to be introduced in the *Treatise*, it will be unnecessarily incomplete and limited in its usefulness unless some outstanding gaps are filled before it goes to press. It is with this object that the present paper is published.

Renziceras gen. nov.

Type Species.—Hildoceras nausikaae Renz, 1912, p. 607, pl. xiv, fig. 4, and text-figs. 25, 25*a*. (Plate I, fig. 3.)

Horizon and Locality.—Toarcian, Epirus, Greece.

Generic Characters.—A "dimorph" Hildoceratid. The inner whorls are coronate, the sides divergent, bearing strong, simple, distant, *Teloceras*-like ribs which end with a coarse ventro-lateral tubercle. On the last whorl the ribbing changes suddenly to gently falcoid, the tubercles disappear, and the whorl-shape becomes quadrate, the coiling evolute, planulate. Venter unicarinate. Sutures normal Hildoceratid.

Affinities.—Renz (1912, p. 608) remarked that the inner and outer whorls are so different that if they had been found separately two species or even genera would have been made out of them. Fifteen years later he transferred the species from *Hildoceras* to *Bouleiceras* (Renz, 1927, p. 486). The suture differs from that of *Bouleiceras*, however, in having an indented second-lateral saddle and a less

degenerated second-lateral lobe ; and no *Bouleiceras* has a coronate nucleus. The affinities of *Renziceras* are more likely with *Mercaticeras* Buckman (see e.g., Merla, 1933, pl. vi).

PROCEROZIGZAG gen. nov.

Type Species.—*Stephanoceras crassizigzag* Buckman (1892, var. α, pl. xiv, figs. 2, 3, lectotype).

Horizon and Locality.—Lower Bathonian, Zigzag Zone, Broad Windsor, Dorset. Also other Dorset localities, same bed.

Generic Characters.—Large, massive Zigzagiceratinae in which the coronate *zigzag*-stage persists for several whorls and is followed by one or more whole whorls with normal coarse *Procerites*-style ribbing. Aperture simple, without lappets.

Affinities.—*Zigzagiceras zigzag* (d'Orb.), the type species of *Zigzagiceras* Buckman (1902) by original designation, is a small species with lappets, close to the form figured as "*Procerites*" *euryodos* (Schmidt) by Buckman (1920, pl. cliii). The type species of *Zigzagites* Buckman (1922, pl. ccci) is Middle Bathonian and its holotype is almost certainly a poorly-preserved large *Wagnericeras*. No name therefore exists for the group of large forms with simple aperture represented by *Z. crassizigzag* Buckman, of which *Z. pollubrum* Buckman (1921, pl. cclix) represents the outer whorls. The inner whorls of *Z. crassizigzag* were refigured by Buckman in 1922 (pl. cccxxxv) correctly named, but erroneously called " holotype ". There was no holotype of this species, and the specimen figured in 1922 was not one of the syntypes figured in 1892, nor even a topotype (it came from Crewkerne). Another species of *Procerozigzag* is *S. pseudoprocerum* Buckman (1892, pl. xiv, figs. 4, 5), of which *Z. rhabdouchus* Buckman (1922, pl. ccc) is probably a synonym.

LYCETTICERAS gen. nov.

Type Species.—*Lycetticeras lycetti* sp. nov. (Plate I, fig. 2.)

Horizon and Locality.—Middle Bathonian, Great Oolite, Minchinhampton, and Fuller's Earth Rock, Dorset and Somerset.

Generic Characters.—Inner whorls perisphinctoid, somewhat evolute, rounded, with irregular feeble biplicate ribbing. After 20–30 mm. the primaries fade away and only ventral ribbing remains, as in *Morrisiceras*, or coarse undulation, as in some *Pachyceras*. Outer whorls become laterally compressed and the last whorl coils excentrically and loses all ribbing. Sutures as in some *Morrisiceras*.

Affinities.—The type species, which cannot be figured in my current monograph on the English Bathonian Ammonites for a year or two, is hitherto undescribed, but it is the most characteristic species of a group which includes *Morrisiceras comma* Buckman, *M. sknipum* Buckman, and others. The genus differs from *Morrisiceras* by its

perisphinctoid nucleus and the flattening and excentric coiling of the outer whorl. Some species are homoeomorphs of Callovian *Pachyceras*. Whether it be placed in the Tulitidae or Macrocephalitidae is a matter of opinion ; and the possibility cannot be excluded that it is an aberrant offshoot of Perisphinctaceae, comparable with the Morphoceratidae. Provisionally it is retained in Macrocephalitidae beside *Morrisiceras*, from which it has not hitherto been separated.

NEOMORPHOCERAS gen. nov.

Type Species.—Ammonites chapuisi Oppel (references below). (Plate I, fig. 4.)

Horizon and Locality.—Upper Oxfordian, Transversarius Zone, S.W. Germany, S. France.

Generic Characters.—Dwarf, constricted, ribbed, *Morphoceras*-like perisphinctids. The inner whorls are involute, sphaerocone ; the outer whorl or whorls gradually become evolute, contracted.

Affinities.—The type species was refigured from the Transversarius beds of Trept as a *Cadoceras* by de Riaz (1898, p. 39, pl. xvi, figs. 2, 3), and from Pamproux as a *Sphaeroceras* by Gérard (1936, p. 214, pl. xiv, figs. 3, 4). The contemporary and allied *Ammonites collinii* Oppel was placed by Gérard in *Perisphinctes* (1936, p. 206, pl. xii, figs. 2, 3). There can be no doubt that these species represent a degenerated, dwarfed offshoot of the Perisphinctinae, along the lines travelled in the Bajocian-Bathonian by the Morphoceratidae and repeated in the Lower to Upper Oxfordian by *Mirosphinctes* Schindewolf (from *Grossouvria*) and in the Kimeridgian by *Enosphinctes* Schindewolf and *Sutneria* Zittel (from rasenids). Earlier analogues in the Lias are *Pimelites* and *Diaphorites* Fucini, which presumably are degenerated dactylioceratids.

Mirosphinctes, the other Oxfordian example of this trend, differs from *Neomorphoceras* in having irregular, rursiradiate (grossouvrid) ribbing, with many parabolic nodes on the inner whorls, and a flanged peristome with lappets.

PROGERONIA gen. nov.

Type Species.—Perisphinctes progeron von Ammon (1875, p. 181, pl. i, fig. 2).

Horizon and Locality.—Lower Kimeridgian, Tenuilobatus Zone, Bavaria.

Generic Characters.—Large, evolute perisphinctids of the Lower Kimeridgian, with biplicate and triplicate ribbing which modifies gradually as in *Arisphinctes* of the Upper Oxfordian.

Affinities.—Differs from contemporary *Lithacoceras* in being more evolute, less compressed, and lacking the fine, sharp, fasciculate ribbing.

Probably derived from *Arisphinctes*, whereas *Lithacoceras* is derived from *Discosphinctes*. For a photograph of a form close to the type species see Schneid, 1914, pl. i, fig. 6 (Pseudomutabilis Zone, Franconia). To the same genus belong *P. eggeri* von Ammon and *P. ernesti* (Quenstedt) as figured by Schneid (1914, pl. i, fig. 5). Similar forms occur in the Jubaila formation in central Arabia. This group has been included by some authors in *Planites* de Haan, but the type species of that (if it is to be retained as a genus at all) is *Nautilus polygyratus* Reinecke, an *Orthosphinctes* (see Arkell, 1951, p. 194). The group of *P. progeron* von Ammon and *P. eggeri* von Ammon was named *Ammonia* by Ilovaisky and Florensky in 1941, but that generic name was three times preoccupied.

VIRGATAXIOCERAS gen. nov.

Type Species.—*Virgatosphinctes setatus* Schneid (1914, p. 165, pl. v, fig. 5 ; pl. vi, fig. 4).

Horizon and Locality.—Middle Kimeridgian, Beckeri Zone, Bavaria.

Generic Characters.—Ataxioceratids which show normal ataxioceratid style of ribbing at an early stage but later develop virgatotome ribbing so as to resemble *Subplanites*.

Affinities.—The type species and its allies (*V. comatus* Schneid, etc.) in the Beckeri Zone, figured by Schneid as *Virgatosphinctes*, are believed to be derived from forms such as *Ataxioceras* (not *Decipia*) *lautum* Schneid (1944, pl. viii, figs. 5, 6, 7) of the upper Tenuilobatus Zone (= Mutabilis Zone) and to be ataxioceratids despite resemblance of the middle and outer whorls to *Subplanites* of the higher zones. *Subplanites* (derived from early *Lithacoceras* or other normally ribbed perisphinctids) has regular biplicate ribbing on the inner whorls and develops the virgatotome style of branching only later. Consistently with the presumed absence of the Beckeri Zone in England, *Virgataxioceras* has not been found in this country, but it has been figured (under the wrong generic name " *Divisosphinctes* " *fallax*) from Russia by Ilovaisky & Florensky. There too its horizon is above the main Aulacostephanus Zone and below the *Subplanites* beds, or so-called " Wetlianian stage " ; i.e. in beds correlated with the Beckeri Zone. (*Subplanites* Spath, 1925, = *Sokolovia* Ilovaisky, 1934, = *Ilowaiskya* Vialov, 1940.)

TITHOPELTOCERAS gen. nov.

Type Species.—*Aspidoceras moriconii* Meneghini (1885, pl. xxii, fig. 2). (Plate I, fig. 1.)

Horizon and Locality.—Tithonian of Ancona province, Italy.

Generic Characters.—Inner and middle whorls depressed, coronate, with irregular ribs bearing a single row of median to ventro-lateral

tubercles; venter more or less smooth. Outer whorl resembling certain peltoceratids, with swollen, distant, simple ribs bearing lateral bullae and passing strongly over the venter.

Affinities.—Inner whorls of either the Italian or a closely allied species have been figured from the Tithonian of Majorca as *Himalayites? parakasbensis* (Fallot & Termier, 1923, p. 10, pl. i, fig. 1), together with another species, *H. (?) laevis* F. & T. (fig. 3). They remarked that attribution to *Himalayites* was questionable and provisional; but probably *Tithopeltoceras* was rightly placed in Himalayitidae. Another species of the same genus, differing in several characters, has been figured from the Lower Tithonian of Andalusia as *Peltoceras edmundi* by Kilian (1889, p. 675, pl. xxxxii, fig. 5). Possibly it also accounts for a record of *Peltoceras* in the Kimeridgian of Greece (Renz, 1927, p. 493).

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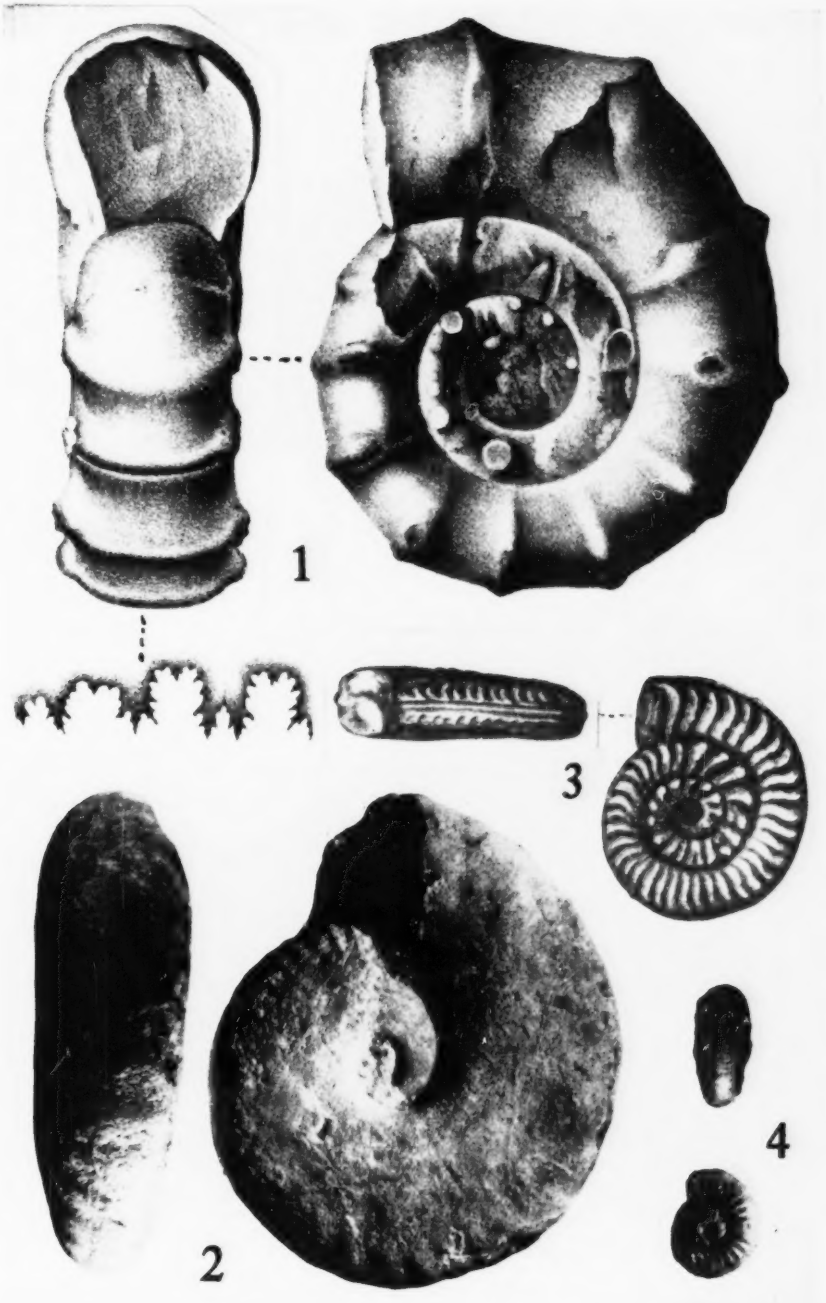
EXPLANATION OF PLATE I

FIG. 1.—*Tithopeltoceras moriconii* (Meneghini), Tithonian, province of Ancona, Apennines. Original figures after Meneghini, 1885.

FIG. 2.—*Lycetticeras lycetti* sp. nov. Holotype, Middle Bathonian, Great Oolite, Minchinhampton. Sedgwick Museum no. B 3793. × 0·5.

FIG. 3.—*Renziceras nausikaae* (Renz), Toarcian, Epirus, Greece. Original figures after Renz, 1912.

FIG. 4.—*Neomorphoceras chapuisi* (Oppel), Upper Oxfordian, Transversarius Zone, Trept, Isère. After de Riaz, 1898.



NEW JURASSIC AMMONITES.

The Spread of the Continents

By G. F. S. Hills

Abstract

It is generally accepted that the continents contain more radioactivity than the Pacific floor. The two continents, Laurasia and Gondwanaland, would therefore expand the rocks below, relative to that floor. The plastic substratum under the continents would be forced higher in their centres than at their Pacific margins. It would creep towards those margins and would carry part of the overlying granite to them, piling it high at their margins and thinning it at their centres. The plastic substratum would continually carry its heat to the cold Pacific substratum and render it plastic into which the continents would be impelled.

THE continents of Eurasia and Africa are surrounded, except where they adjoined in the ancient Tethys, by oceans and seas—the Arctic, the Atlantic, and the Indian Oceans and the festoon seas of Asia from the South China Sea up to the Bering Sea. Those oceans and seas are geological young seas, and are surrounded by continents, islands, and submerged ridges, which face the geologically old Pacific Ocean. That in itself implies that the continents have spread outwards from one or more centres. In support there is the evidence from the organisms found in the different continents which suggests that the present continents may have originated from one of two hypothetical continents which have been named Laurasia and Gondwanaland separated by a sea called the Tethys Sea. Again in support there is the evidence from the convection currents in the liquid magma that at first two continents were formed at the two poles, which later floated towards the equator, where gravity is least (Hills, 1947), and finally there is the effect of radioactivity in dispersing those two continents over the earth, which is the subject of the present paper.

It was concluded, from the evidence of the organisms, that the present continents must have had some land link between them and at first it was suggested that the continents were fixed in their present positions, but connected by land bridges, along the shallow seas or land of which the organisms could migrate. But agreement could not be reached where and what size the land bridges were, nor how granite bridges could have sunk and leave no trace on the ocean floor. An alternative method of connection was suggested by Wegener who supposed that the continents were moveable and had drifted apart, but he could not point to any force sufficient to drive them through the strong Pacific floor.

Gutenberg (1936, p. 1587) has suggested a theory, based on seismology, which he has called " The Fliesstheorie " or the theory of continental flow. He described it (1939, p. 210) as follows :—

> " Whereas Wegener has assumed that the continents are drifting icebergs, Gutenberg postulates plastic flow (including creep) in both continents and the substratum."

and on the same page :—

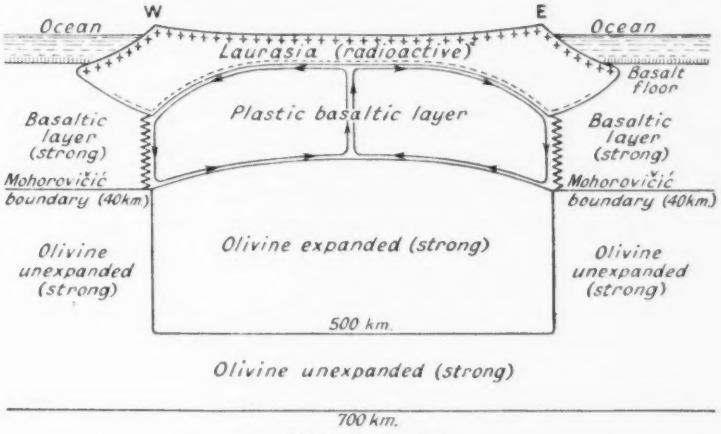
> " Here too the most serious problem to be solved involves the forces that have been produced, and may still be causing, continental displacements."

and

> " As has been pointed out repeatedly, such forces must exist, but we do not know them."

The object of this paper is to point to a force that now exists and the manner in which it has operated to spread the two continents, Laurasia and Gondwanaland, over more than half the earth as Gutenberg postulates, further providing " land bridges " over which the organisms could migrate. The force is the heat generated continuously by radioactivity in the continents over 2,000 million years. For the reasons based on laboratory research and on theoretical grounds (Hills, 1947), radioactivity in the continents is much greater than that in the Pacific floor. It follows that the heat generated by the radioactivity in the continents must have expanded the rocks deep below, and therefore raised the continents and the substratum relative to the Pacific floor. Jeffreys (1932) has calculated that this relative rise would be by the order of 10 km. In doing so he assumed that the continents had not spread but remained compact. While the continents are of strong granite the substratum is plastic and capable of horizontal movement as shown in Airy's (1855) theory of mountains. The substratum is pushed up by the expanded rocks below into a flattened dome-shaped form, high under the centre of the continents and low at the Pacific margins where the heating effect of the continents was less. A viscous liquid cannot remain in that form. The viscous substratum therefore creeps away down to the margins in the endeavour to obtain a level surface, like a lump of putty. In its creep it carries with it by the intense friction some of the under surface of the overlying strong continent. There must therefore through the ages have been a great accumulation of granite at the Pacific margins and a corresponding thinning of the granite in the interior of the continents (Text-fig. 1). The great weight of the material carried to the margins, granite and the substratum, disturbed the balance which existed in the earth and pressed out the lower levels of the substratum from the margins back to the centre of the continents and added once more to the height of the dome. The substratum therefore circulated as a viscous liquid, the circulation being by gravity, though the prime mover is the expansion of the rocks deep below.

The substratum has two ways by which the heat which it received from the continents can leak away : one is to the olivine rocks vertically below which has been considered by Jeffreys ; the other is horizontally to the strong Pacific rocks which surround the substratum. The continent has continually to replace the heat which leaks away in order to maintain the equilibrium temperature between the continent and the substratum. The substratum being kept continually hot and continually moving against the cold Pacific rocks would bring them to the same temperature as itself, that is, it would render them equally



TEXT-FIG. 1.—A hypothetical section of Laurasia. Radioactivity expands the olivine which domes the basaltic layer and also renders the latter plastic. The creep by gravity of the plastic layer to the margins thins the granite in the interior and piles it up at the margins. The zig-zag lines indicate the meeting of the hot basaltic layer with the cold basaltic layer which meeting gradually extends outward. Granite + + +, uncrystalline granitic — — —.

plastic as they differ only in their temperatures. The accumulated granite being impelled by the flow of the substratum would then enter the rocks of the Pacific margin which have been rendered plastic. The thin top crust of crystalline basalt which probably forms the Pacific floor would, being heavier, sink in the plastic basaltic layer.

There is another means by which radioactive heat can reach the Pacific rocks. The accumulation of granite in a ridge on the Pacific margins brought with it an accumulation of radioactivity. The radioactive temperature of the roots of the granite ridge would be increased by the square of the thickness of the granite. The granite of a ridge with its roots would become hot and would be pressed against the Pacific rocks. The latter would become hot and would, like the substratum, become plastic into which the granite ridge would be impelled.

The denudational effects of the winds would act differently on the east and west coasts of Laurasia and Gondwanaland owing to the rotation of the earth. The tropical wind from the east which crossed the vast expanse of those continents would bring little rain to the western ridges. In consequence, those ridges on the west coasts would be high. The present coastal ridges of the Americas and Canada are not folded mountains, they are in part batholithic. As the ridges moved into the Pacific rocks, rendered plastic, the whole continent moved westward with the moving substratum.

On the east coasts there were probably no ridges as the rain wore them down as fast as they arose. There are no coastal ridges parallel to the coast to-day. On the other hand there would be much sediment deposited in the Pacific Ocean. As the sediment would have the same radioactivity as the granite, the thickness of the sediment combined with that of the granite, on which it was deposited, would greatly raise the temperature of the lower level of the continent which lower level contained much water. The sediment would slowly press down the granite until the substratum broke through the continent and the weak sediments above. Then the substratum released from the immense pressure of the whole continent would issue as lava on to the western Pacific floor. It would flow far down the Pacific floor until its forward edge chilled into a great dam such as is found in the continental side of the Tuscarora and the Tonga deeps.

The continents of Laurasia and Gondwanaland must have spread in consequence of the heat of radioactivity generated over 2,000 million years. The expansion of the deep rocks which Jeffreys has pointed out and the horizontal creep of the plastic substratum in levelling itself inevitably led to a spread. The continents spread radially in all directions except across the Tethys where they meet. They spread westwards towards the Americas, and eastwards towards Asia and Australia ; northwards and carried Spitzbergen with its coals and Greenland with its luxuriant fossil vegetation into their present high latitude ; and southwards and carried Antarctica with its plant remains 300 miles from the south pole. Radioactivity in the course of 2,000 million years would tend to equalize the distribution of its heat over the surface of the earth by a more equal distribution of the continental material. It reverses the concentration of radioactivity that the convective flow of the magma to the poles brought at the time of the formation of the continents.

The spreading process could not go on indefinitely. When the granite has been thinned in the interior below a certain limit the substratum below, because of less heat transmitted down, could no longer be plastic and all movement would cease. There would therefore be a limit to the downwarping. Suppose for instance that in a region the

granite was originally 15 km. thick, as in Europe to-day (it was probably thicker before the spread) and suppose that the whole of this granite, density 2·65, were thinned, it would require 14 km. of the basaltic substratum, density 2·85, to replace it. The surface would then at most be 1 km. below the surface of Europe. The downwarped granite cannot even in those extreme circumstances, when it has been wholly replaced, be more than 800 metres below the sea, it would probably be much less ; the sea would therefore in parts be a shallow sea. It will therefore be seen that the spread of the continents could lead only to shallow oceans in their thinnest parts. This throws light on J. W. Gregory's remark (1930) that the floor of the North Atlantic ocean is strewn widespread with the shells of organisms far below their habitat, that is that that floor was once the floor of a shallow sea. Seismological observations on surface earthquake waves indicate that the floor of the North Atlantic Ocean contains a considerable amount of continental material. R. M. Field (1936), who is quoted by Gutenberg (1936, p. 323) in his work already mentioned, says :—

> "The analysis of earthquake waves, therefore, not only suggests that the Atlantic be everywhere underlain by a considerable thickness of continental rocks, but also intimates that the Pacific continental margins are of much greater structural significance than those of the Atlantic . . . It is possible, therefore, that the sub-Atlantic lithosphere constituted a vast area of down-warped pre-Cambrian and Palaeozoic geology, fully comparable in the complexity of its subsidiary stratigraphical, structural, and palaeo-geographical features, to the up-warped pre-Cambrian and Palaeozoic geology of the surrounding continental areas . . . It is not implied that the downwarping of this great pre-Mesozoic continent of Atlantica was relatively rapid or that it took place all at once . . . What is implied, however, is that though the pre-Cambrian and Palaeozoic history of the earth, the Atlantic region was characterized by seas, lakes, rivers, mountains, sediments, marine, and terrestrial organisms, respectively similar to and co-existent with those of the continents."

The Atlantic region in Mesozoic times may have been like the region in Palaeozoic times as described by Field, though probably more extensive. It might then afford for migration shallow seas for marine organisms and land for land organisms. "Land bridges" would have existed so long as the region of the downwarped granite was an undulating region, in some places above and in others below the sea. The dispersal of the two original continents by the slowly acting radioactivity must have been an exceedingly quiet process which occasioned no catastrophic deepening of the downwarped granite ; some other force must have acted to produce that deepening.

The Atlantic and Indian Oceans to-day are deep oceans, 48 per cent and 59 per cent of their areas lie at depths 4 to 6 km. below the surface. The question is how did that downwarped granite, which the theory advanced and J. W. Gregory's observations show, become in parts deep oceans ? Those deep parts in all probability were due to the vast flows of lava which emerged from the eastern coasts of Laurasia and Gondwanaland (Hills, 1947). Those vast flows of lava must have come from somewhere under the continents. The upper surface of the substratum under Laurasia when the North Atlantic was a downwarped region must have been of a mountainous nature. Under the downwarped North Atlantic floor the substratum would be less than 10 km. below the sea surface. It is only 15 km. below the surface of Europe but under the granite ridges of the Pacific margins of America and Asia it was perhaps 30 km. below sea level. The difference between the level of the substratum under the Atlantic region and under the Pacific margin may have been of the order of 20 km. So long as it was sealed in by the strong continent and the strong rocks under the Pacific floor the plastic substratum could not escape or level itself. When, however, a large opening in the western Pacific margin occurred (through the weight of sediment deposited) which cannot be sealed by chilling, it flowed as lava on to the Pacific floor being released from the immense pressure of the whole continent above.

A level surface is the natural surface for a liquid like the lava, it therefore pours upon the Pacific floor which is already in balance with the continents and creates suddenly a new floor which is not in balance. As the natural state of the earth is one of balance, some material must eventually have been forced out from beneath the Pacific floor to take the place of the substratum that has been pressed out from under the continents. The question is from what place under the continents did that substratum come ? It must have come from the places where it stood highest, that is in the downwarped granite regions. To restore the balance the substratum under those areas must have been replaced by the material that had been pressed out from under the Pacific floor. That material could not have been the strong basaltic rocks as they could not have been moved horizontally. It must have been those weak rocks, probably the deep olivine, which have been placed at over 700 km. deep (Jeffreys, 1939). The density of that weak olivine is very great about 4·4 to 5·4 (Bullen, 1936), depending on the depth at which the movement took place. Therefore a lowering of parts of the downwarped Atlantic and Indian Ocean floors by 4 km. is possible ; such a lowering by the advent of the dense olivine would be necessary to keep them in balance with the main mass of the earth as a whole.

There is, moreover, some evidence that some rise of the dense olivine

may have taken place under the Atlantic and Indian Oceans for Gutenberg (1939, p. 385) says :—

> " Except for the Pacific basin and possibly the Arctic basin, a sudden change in material has been found at depths ranging from 20 km. in the Atlantic and Indian Oceans to 40 km. or slightly more in the central parts of the continents."

He is referring to the Mohorovičić level which separates the basaltic substratum from the upper part of the olivine rock. This indicates that the Mohorovičić level has, under those oceans, been raised by an inflow of 20 km. of the deep and weak olivine. This rise seems high but it is in the direction required.

Research is necessary to account for other matters, such as the Atlantic ridge and the high level of Eastern Africa. The theory sketched of the spread of the continents and the formation of the deep Atlantic and Indian Oceans has the merit of being in accord with the known physical data and does not involve any *ad hoc* hypotheses.

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63 WEST END AVENUE,
PINNER, MIDDX.

Note on Factors Governing the Porosity of Wind Deposited Sands

By J. Kolbuszewski

Abstract

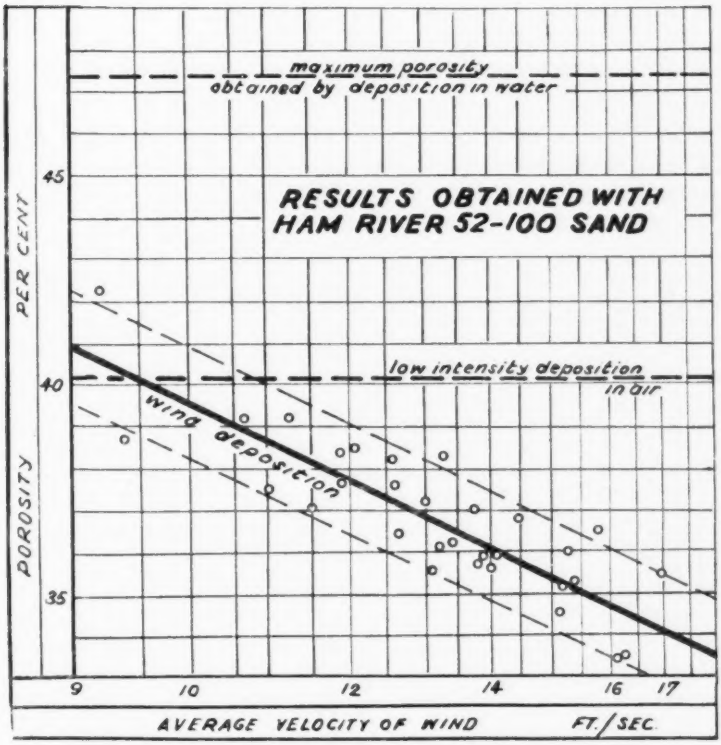
After establishing average velocity of wind/average porosity curve for wind deposited sands, where it was shown that low wind velocity produces higher porosity than high wind velocity, further investigation was made and sands of various characteristics were used. It was established that the velocity of wind/porosity of deposit relationship is a more complicated function than was previously expected and some of the reasons are explained. The first indication of the influence of shape of the grain and the specific gravity of grains on the obtained results is registered. Further steps in the research are indicated.

With studies of sand oolites and other solid particles, a knowledge of relationships between velocity of fall, intensity of deposition, and porosity might help to classify the conditions under which the deposit was or is formed. The results described in this paper, combined with those indicating how porosity is formed in "vertical" deposition (Kolbuszewski, 1948, *a* and *b*, 1950), should at least make the laboratory control of sedimentation easier.

To provide information concerning the porosity of wind-deposited sands, research on packing and density of wind deposits was started in the author's laboratories and the first general relationship of average wind velocity/average porosity, obtained for a sand having similar characteristics to the Lybian Desert sand, was published in 1950. The relationship obtained for Ham River Sand 52–100 BSS (Text-fig. 1) shows that the trend of the curve approaches the lower limiting porosity with increased velocity of wind and at very high velocity goes below that limit. The position of the individual points on the curve averaged from many experiments indicated that other factors would have to be investigated.

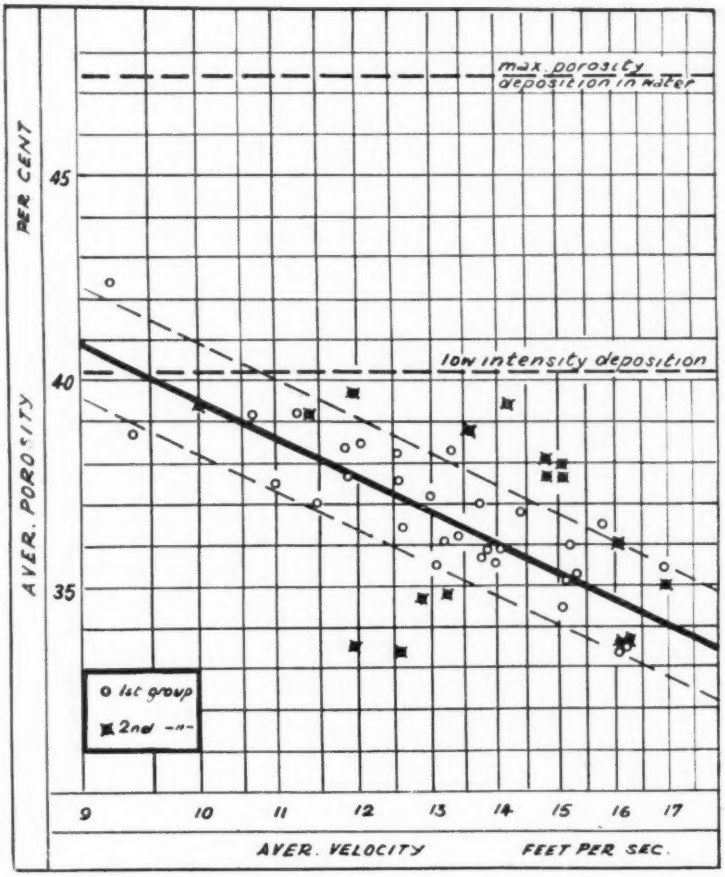
The new series of experiments, in the same wind tunnel, gave a family of points (Text-fig. 2) which when compared with those previously obtained indicated that the porosity/velocity of wind relationship must be a more complicated function than was previously expected. The possibility of obtaining small porosity with small velocity of wind, similar to that obtained by much stronger wind, became apparent and led to a further search for the reason of this behaviour.

A more "sensitive" (Kolbuszewski, 1948 *a*) sand had to be selected, and Leighton Buzzard 18–25 BSS sand was used for the further investigations. The results obtained with Leighton Buzzard 18–25 BSS sand (Text-fig. 3) compared with those previously obtained for Ham River 52–100 BSS show the difference in sensitivity.



TEXT-FIG. 1.

It is not intended to describe in detail the technique of experiments and measurements. It should be sufficient to mention that the volume of the supply of sand in the tunnel (lb./sec/cross-section) was kept constant and that intensity of deposition (lb./sec/sq. ft.) was the function at initial stages of roughness of the surface of the bottom of the tunnel and the velocity of wind and the characteristics of the extreme top layer of the deposited sand. In all experiments sand deposited in the tunnel adopts the shape of an aerodynamic dune. It should be mentioned that the "accidental" shape of the initial deposit on the bottom of the tunnel influences the tunnel deposition. "Accidental" is used in the description of the initial deposit because the individual grains first deposited, when the deposition starts, in the tunnel, assume accidental resting-places and form various patterns on the bottom of the tunnel and this pattern controls the shape of the growing dune during the first stages of each experiment. The sand-paper used in the tunnel to simulate natural conditions was not sufficiently elastic to



TEXT-FIG. 2.—First and the second group of experiments compared. Sample : Ham River Sand 52-100 B.S.S.

provide a base similar to that existing in nature, although influence of this factor should not be exaggerated. It was observed that impact has primary effect on windward, and saltation on leeward parts of the dune. This difference decreases in significance with decrease of the diameter of the grains.

It was also found that during deposition grains of larger diameter or higher specific gravity were left at the front of the dune and the smaller ones moved down-wind and were later deposited.

It may be mentioned that the heavy grains existing in the Ham River sands (mentioned in the first report on this research) caused considerable disturbance in the readings of porosity due to unequal

distribution of that fraction in the samples used, and had to be eliminated. A special magnetic separator was designed to affect an almost complete elimination of heavies, predominantly haematite.

Generally in this part of the experiments the relation of wind velocity to the resultant porosity expressed as

$$n = f\ (v)$$

where n = porosity (per cent); v = velocity of wind (ft./sec.) was investigated, and the special attention was paid to the intensity of deposition q_d expressed as

$$q_d = f\ (R,\ v,\ D,\ \rho_s)$$

where

R = resistance to motion.
v = velocity of wind.
D = diameter of grains.
ρ_s = specific gravity of grains.

Using dimensional analysis the following final formula was obtained at this stage for the velocity of wind-porosity relationship

$$n = 100 \times \left(1 - \frac{p}{C_v \rho_s D}\right)$$

where

n = porosity in per cent.
ρ_s = specific gravity (density) of grains.
D = diameter of grains.
C_v = volume coefficient.
p = resultant wind pressure on grain.

The above formula was arrived at by substituting in the well-known formula for porosity

$$n = \left(\frac{V - \frac{W}{\rho_s}}{V}\right) \times 100$$

where

V = volume of soil.
W = weight of soil.
ρ_s = density or specific gravity of grains.

the expressions found from the experiments and dimensional analysis for V and q_d :—

$$V = \frac{C_v D\,(q_d A T)}{\rho}$$

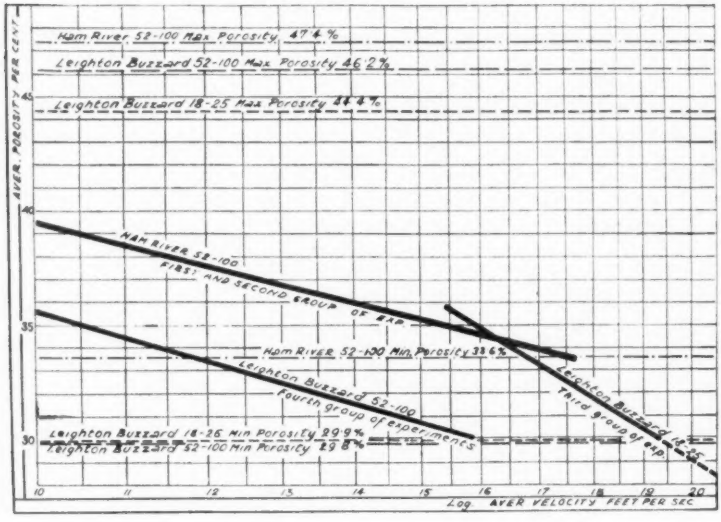
$$q_d = C_q \frac{v^3 \rho}{D} \sqrt{\frac{\rho}{\rho_s}}$$

where

A = area.
T = time of flow.
ρ = density of air.
C_q = intensity of deposition coefficient.

It was concluded at this stage that in the above work the intensity of deposition had no influence on porosity.

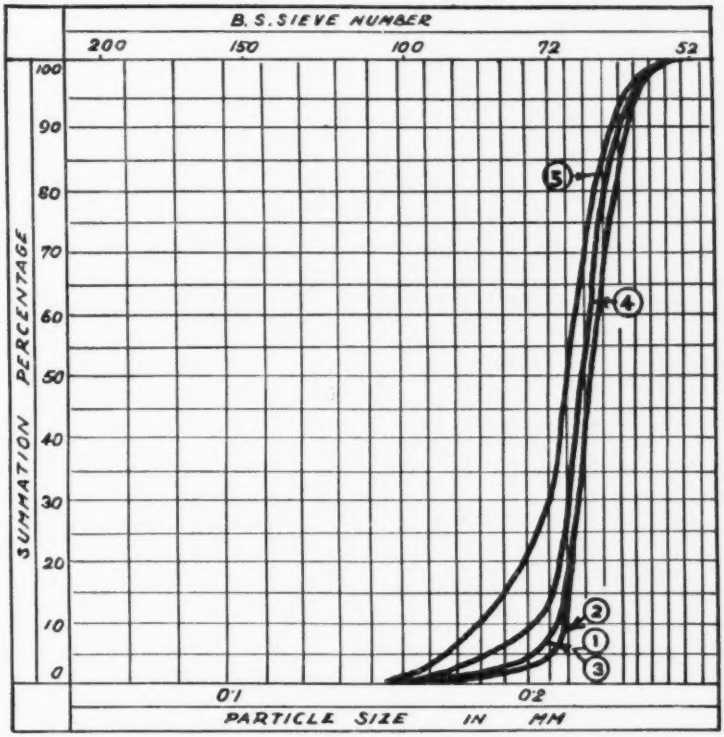
Many difficulties were met in finding coefficient C_q in the formula for q_d. The experiments were carried out with the intensity of supply



TEXT-FIG. 3.—Porosity-velocity of wind relationship for three samples.

of the sand to the tunnel approximately constant, and as it was thought that the conditions in the tunnel were to a certain extent artificial, the tunnel was redesigned to give more natural conditions of deposition, and the problem of the intensity of deposition further investigated.

To get a clearer picture of the distribution of the porosities along the dune in the tunnel (up to now average porosity was measured) and at the same time to investigate further the influence of other factors such as specific gravity and shape of grains, Leighton Buzzard sand 52–100 BSS was used, and some of the new results obtained are shown by the L-B-52/100 curve on Text-fig. 3.

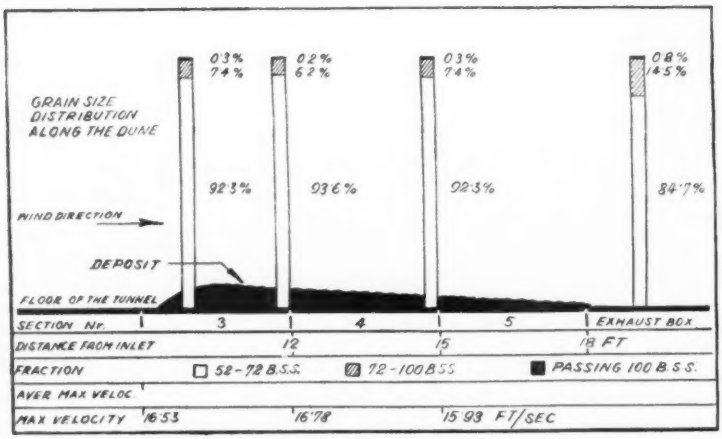


TEXT-FIG. 4.—Grain size analysis. Samples taken from deposit along the wind tunnel. Sand used : Leighton Buzzard 52-100 B.S.S.

1. Windward part of dune—upper end of section 3.
2. Leeward part of dune—between sections 3–4.
3. Leeward part of dune—down of section 4.
4. Exhaust box } two experiments.
5. ,, }

The obtained curve for L-B-52/100 may be now compared with the curve obtained for Ham River 52–100 sand. The differences between these two sands are as foilows :—

Sand	Specific Gravity	Roundness	Sphericity	Max. Porosity	Min. Porosity
Ham River 52–100 BSS	2·7	0·385	0·785	47·4%	33·6%
Leighton Buzzard 52–100 BSS	2·6	0·410	0·810	46·2%	29·8%



TEXT-FIG. 5.

These differences resulted in moving the velocity/porosity curve of Leighton Buzzard about 4 per cent below the Ham River curve. It is interesting to compare this result with the similar results of " vertical deposition " (see reference Kolbuszewski, 1948 *a*).

The influence of diameter of grains may be seen from the comparison of L-B sands 18–25 and 52–100 (Text-fig. 3).

Sand	Specific Gravity	Roundness	Sphericity	Max. Porosity	Min. Porosity
Leighton Buzzard 18–25 BSS	2·6	0·410	0·810	46·2%	29·8%
Leighton Buzzard 52–100 BSS	2·6	0·470	0·840	44·4%	29·9%

At this stage of the research the distribution of porosities along the dune was investigated and typical results are shown on Text-figs. 4 and 5.

To explain the influence of the shape of grain on the velocity of wind/porosity relationship the following can at the present state of research be stated :—

Dimensional analysis is of no help because both roundness and sphericity are dimensionless ; an attempt to find dimensions gives

$$\text{Roundness} = \frac{L^{-1}}{L^{-1}}$$

$$\text{Sphericity} = \left(\frac{L^3}{L^3}\right)^{1/3}$$ and these cancel.

The following procedure of introducing a shape factor covering both roundness and sphericity simultaneously will solve overall question of shape.

For the purpose of calculations it is possible to replace individual grains by imaginary spheres of the same material and of such diameter that they behave in the stream of air as an average sand grain. This is done by introducing the shape factor β.

This shape factor is the ratio of the nominal diameter (d) to assumed nominal diameter of sieve aperture (D)

$$\beta = \frac{d}{D}$$

or

$$d = \beta D$$

Nominal diameter denotes diameter of sphere having the same volume as a grain.

The nominal size of sieve aperture for given grains was estimated by passing them through a series of sieves. To obtain diameter of sphere, equivalent to given sand grain, 3,000 to 10,000 grains were counted by under a microscope, their weight recorded, and the average weight of one grain calculated. Volume of the " average " grain was computed according to the specific gravity of the investigated sand.

$$V = \frac{W}{\rho} = \frac{\text{weight}}{\text{spec. gravity}}$$

as spheres

$$V = \frac{1}{6}\pi d^3$$

diameter of grain

$$d = \sqrt[3]{\frac{6}{\pi} V} = \sqrt[3]{\frac{6}{\pi}\frac{W}{\rho}}$$

Introducing now β to the previously mentioned equation for porosity we get

$$n\% = 100 \times \left(1 - \frac{p}{C_v \rho_s \beta D}\right)$$

Using the above equation and the experimental results the following was established in connection with the shape (sphericity and roundness) of grain :—

(*a*) Force on grain—the bigger $(\beta D)^2$ the bigger force acts on it.
(*b*) Resistance in motion—the bigger (βD) the bigger the resistance.
(*c*) Intensity of deposition—the bigger βD the smaller intensity.
(*d*) Volume of deposit—the bigger βD the bigger volume.
(*e*) Porosity of deposit increases with βD.

An attempt is now being made to split β and to explain separately the influence of roundness and sphericity using sands, natural and artificial, with the same specific gravity and keeping either roundness constant and changing sphericity or changing roundness and having sphericity constant.

The author would like to thank his two former students, Messrs. J. Tuora and J. Kozera, who performed the experiments under his direction, and Dr. A. W. Skempton and Mr. A. W. Bishop for their interest and advice. Thanks are due also to Professor S. C. Redshaw for research facilities.

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Magnetometric Mapping for Haematite in South Wales

By C. R. K. Blundell

Abstract

In the search for large deposits of haematite and other feebly magnetic minerals, it is suggested that mapping the magnetic residuals may be of greater value than mere linear traverses. Not only is the method more suitable for exploring virgin areas, but it also affords a means of differentiating between the effects of large deeply buried masses and small objects at shallow depths. At the same time, the graphical expression of the results on the map becomes more easily intelligible.

The application of the method to known haematite ore-bodies in South Wales has yielded striking results and the extension of the survey into an unexplored area indicates the possibility of proving at least one further large haematite deposit.

Introduction

A NUMBER of attempts have previously been made to locate haematite deposits magnetically both in South Wales and in Cumberland (Hallimond & Whetton, 1939, p. 1). The technique usually employed has been that of measuring variations in the value of the vertical force along selected linear traverses. The only correction applied to the field observations seems to have been that for the diurnal variation. The results of such surveys have usually been inconclusive and have not led to the discovery of any large new ore-bodies. Similar surveys for feebly magnetic deposits have also been made in other countries (e.g. *Col. Geol. & Min. Res.*, 1951, p. 315).

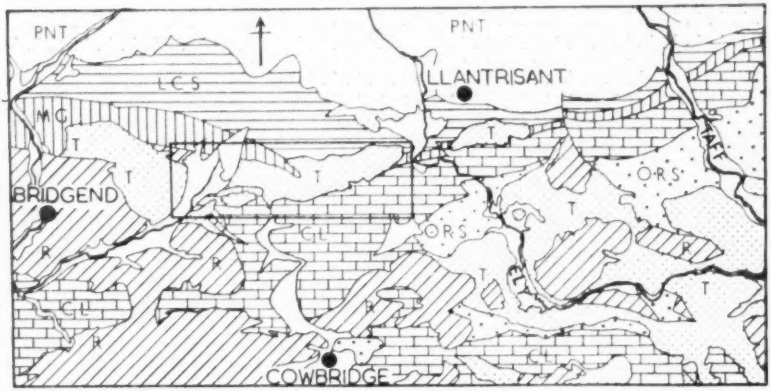
A further survey has recently been made in the Llanharry–Pencoed area of Glamorgan, using a fresh approach to the problem. Corrections were applied for the regional magnetic variation in the area as well as for the diurnal variation. In this way the magnetic residuals were obtained, and they exhibit a very striking distribution pattern. This preliminary note is therefore published in the hope that the method may be tested in other haematite ore-fields.

Geology of the Area

The area described herein is situated about 4 miles north of Cowbridge. It is represented on the Geological 6 inch sheets, Glamorgan XLI N.W. and XLI N.E., and was described by Strahan and Cantrill (1904) in the Bridgend Sheet Memoir. Topographically the ground varies in height between 100 and 300 feet above O.D. Geologically, as shown in Text-fig. 1, the area consists essentially of the Carboniferous Limestone and the Millstone Grit Series dipping northwards at about 35 degrees and largely concealed beneath an unconformable cover of near-horizontal Triassic strata. In places thin accumulations of superficial deposits (glacial drift and river gravels) also occur. The

presence of the overlying Trias, together with the lithological variation in the strata comprising the Millstone Grit Series, and the unconformity existing between this Series and the Carboniferous Limestone, introduces further complications which were not present in some other areas that have been magnetically surveyed for haematite.

The haematite ore chiefly occurs as replacement pockets in the Carboniferous Limestone near the junction with the overlying Millstone



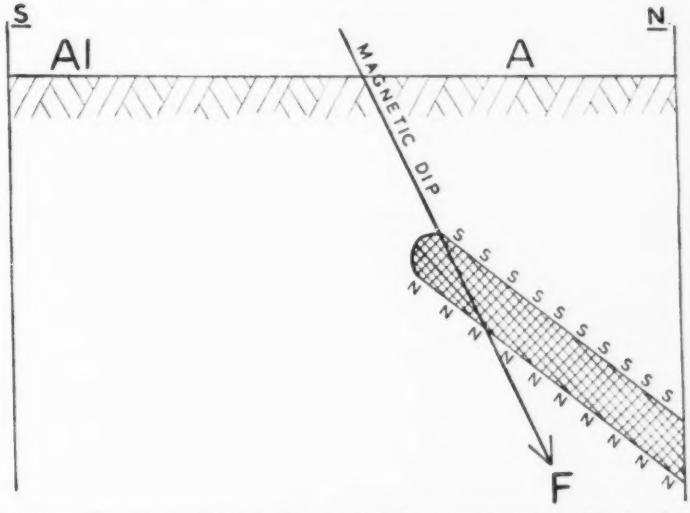
TEXT-FIG. 1.—Geological sketch map showing the position of the present area with respect to other parts of the Vale of Glamorgan and the South Crop of the coalfield. O.R.S. = Old Red Sandstone; C.L. = Carboniferous Limestone; M.G. = Millstone Grit; L.C.S. = Lower Coal Series; PNT. = Pennant Series; T = Triassic; R = Rhaetic and Lower Lias. Scale 4 miles to 1 inch. Geological boundaries after H.M. Geological Survey.

Grit, although small flat sheets of ore also occur near the base of the Triassic strata. The mode of occurrence of the haematite was described and illustrated by Sibly (1927, p. 72). At present two ore-bodies are exploited, the main Llanharry deposit and a small deposit known as the No. 6 ore-body.

Hand specimens of the ore vary considerably in their magnetic properties. Most have no effect when brought close up to the variometer, but occasionally a specimen can be found which will produce a deflection of the needle; the mineral responsible possibly being FeO which is present on average to less than 1 per cent. The magnetic susceptibility of the ore appears to be at least comparable with that of the Cumberland haematite (Hallimond & Whetton, 1939, p. 1). However, the precise values of the magnetic properties of the ore are of comparatively little use for a quantitative interpretation of the results unless the corresponding values for all the associated country rocks are also known.

Technique Employed

Two Watts vertical force variometers were used, one at a base station to record the diurnal variation and the other as the survey instrument to measure the intensity of the vertical force at about 400 stations throughout the area. After preliminary trials, the use of an automatic recording camera at the base was discontinued since it was desirable to know the magnitude of the diurnal variation and the onset of any magnetic storms whilst still in the field. Readings



Text-fig. 2.—At position A the vertical force variometer will give large positive readings due to the south polarity of the upper surface of the ore-body (which dips northwards at less than the angle of magnetic inclination). The repelling effect of the induced north poles of the lower surface will then give rise to negative readings at position A1.

were therefore taken on the base instrument at 10-minute intervals. The survey variometer was also returned to the base at about 2-hour intervals to check any instrumental errors or other discrepancies which might have developed ; none, in fact, were found. All readings taken during periods when the base changed by more than about 20 gamma per hour were disregarded and repeat observations made on a later day.

The survey stations were sited at about 400-yard intervals. As the anomalous parts of the area became apparent, further readings were taken at about 100-yard intervals so as to more accurately delimit the districts with appreciable residual values. Care was taken to site the survey stations beyond the influence of such obvious surface objects as wire fences, electricity pylons, overhead bucket lines, etc.

Tests showed that 50 yards was a safe distance. As a further cautionary measure the stations were usually located at least 30 yards from any hedgerows. In order to test the reliability of the results, repeat observations were taken at about 10 per cent of the stations. Such readings, taken at intervals of between one and four weeks, did not differ by more than 3 gamma after supplying the appropriate corrections for the diurnal variation.

Hallimond & Whetton (1939, p. 17) pointed out that in the case of the Cumberland area, the anomalies due to the haematite were only of the same order of magnitude as those caused by boulders in the glacial drift. In order to overcome any ambiguity due to this or any similar source in the present survey, the conventional practice of measuring the magnetic variation along linear traverses was abandoned. Instead, the results were expressed directly on the map by means of contours showing the magnetic residuals in the area. In this way, although the actual intensity of the anomaly produced by a small object at shallow depth may be similar to that due to a larger but deeper mass, the areal distribution of the anomaly as shown by the magnetic contours at the surface serves to distinguish between the two causes. The areal extent of the anomaly depends on the depth of burial of the magnetic material and, furthermore, the distance between the position of the magnetic High and any corresponding Low is also a function of this depth. Using these considerations therefore, it is possible to distinguish between the effects due to near surface objects and those due to deeply buried large deposits of haematite.

The values of the magnetic residuals were obtained by subtracting the regional magnetic contours from the diurnally corrected value at each station. Graphical methods similar to those employed in gravimetric work (e.g. Jakosky, 1950, p. 416) can be used to obtain the regional magnetic contours, but in the present case they can equally or more easily be drawn by inspection. They consist of smooth, approximately east–west, parallel and equidistant lines drawn in such a way that, after subtracting the regional from the corrected observed value at each station, the number of residuals remaining is a minimum. In this way the correction for the variation of the vertical force with latitude is automatically applied. At the same time, any effects due to the nearby coalfield and to any deep-seated crystalline rocks are also corrected for ; such corrections are essential in view of the fact that the ore-bodies themselves give rise to anomalies of less than 50 gamma.

Results and Interpretation

The results obtained in the present survey are incorporated in Text-figs. 3 and 4. The broad pattern of the magnetic residuals consists

of an approximate east–west belt of negative values in which occurs two distinct magnetic Highs with residuals of up to + 20 gamma. Outside this belt occur two magnetic Lows some 1,200 yards to the south of the respective Highs and showing residuals of more than − 20 gamma.

The east–west belt does not fit in with any geological feature apparent at the surface. It does, however, correspond in direction with the strike of the sub-Triassic outcrop of the Carboniferous Limestone–Millstone Grit junction, to which it may well be related.

The coincidence between the position of the eastern High (A) and the main ore-body, as shown in Text-fig. 3 is remarkable. At the same time, the occurrence of the Low (A1) is considered to be of equal significance, for if an ore-body dipping northwards at less than the angle of magnetic inclination be considered, a Low would, in fact, be expected to occur in the south, as indicated in Text-fig. 2.

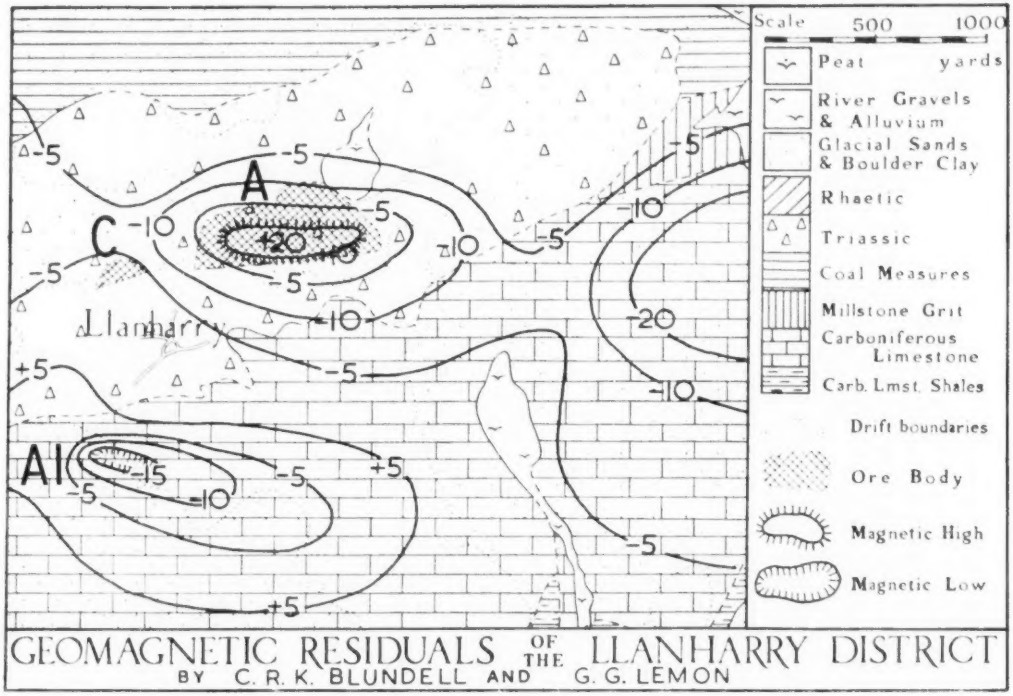
The position of the High (A) and the Low (A1) with respect to the known position of the main Llanharry ore-body is thus very striking. The close parallelism between this magnetic pattern and that further west where the Low (B1) occurs to the south of the High (B) is also notable. It suggests the presence of a further and previously unsuspected ore-body. The pattern of the residuals therefore fully justifies the institution of a boring programme to prove the ground.

The interpretation of the smaller and less striking features of the contour pattern is more ambiguous. Within the present area a small mass of haematite (No. 6 ore-body) occurs at C. This is not large enough to produce actual positive residuals nor to induce a magnetic Low to the south. On the other hand, it does appear to cause a significant local reduction in the negative residuals of the east–west belt. In this connection it is thus possible that other places of reduced negative values within the trough may indicate the presence of further small haematite deposits.

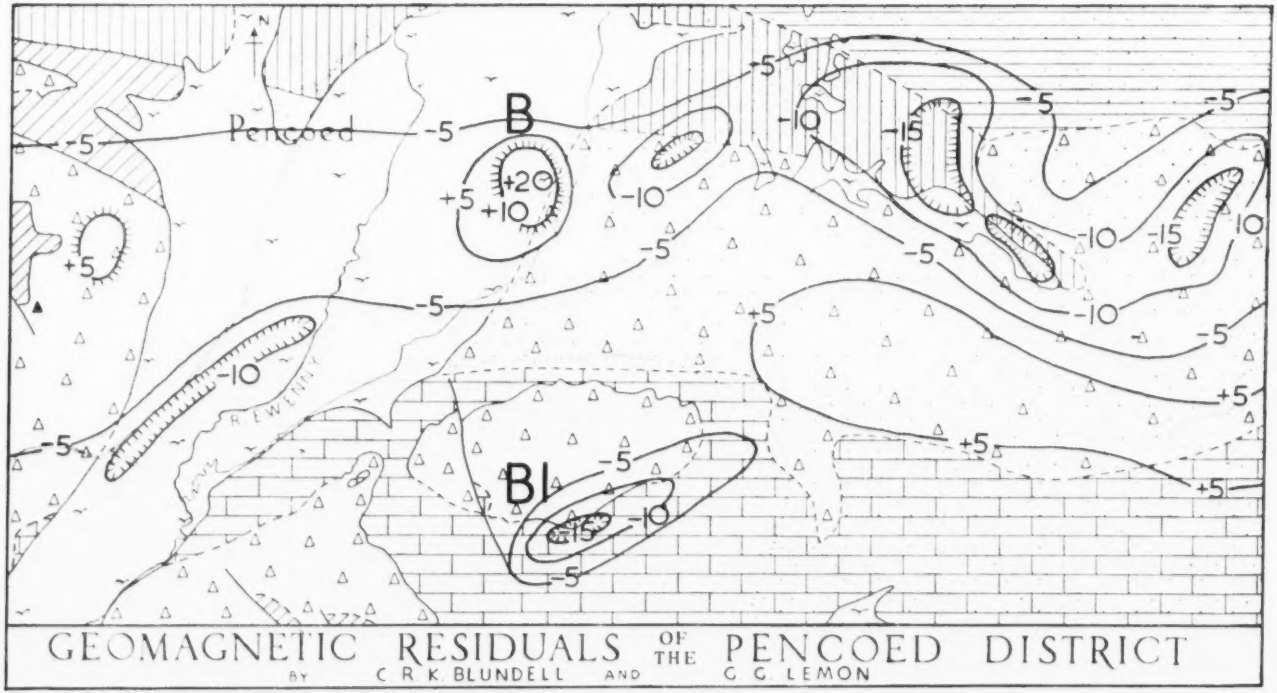
The presence of any ore occurring as large almost horizontal sheets is also difficult to diagnose from the magnetic evidence for such sheets will not, in general, give rise to an induced Low. Further west, beyond the present area, the pattern of the residuals suggests the possibility of such occurrences, but until detailed bore-hole data is available such an interpretation can only be speculative.

ACKNOWLEDGMENTS

The present survey was carried out in co-operation with W. Brynmor Davies, Esq. ; and thanks are due to Messrs. Blackburn and Yeo of the Llanharry Mine for their friendly assistance. The field observations were carried out by Mr. G. G. Lemon and the author, together with Mr. W. J. Henderson, to whom special thanks are due. Grateful



TEXT-FIG. 3.—Map of the eastern part of the area showing the relationship between the magnetic residuals and the haematite ore-bodies. Geological boundaries after H.M. Geological Survey.



TEXT-FIG. 4.—Map of the western part of the area, showing the geology and the pattern of the magnetic residuals. Ornamentation and scale the same as Text-fig. 3. Geological boundaries after H.M. Geological Survey.

acknowledgment must also be made to Professors J. Sinclair and J. G. C. Anderson for providing the necessary facilities, and to Professor L. R. Moore for his valuable criticisms.

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A New Lower Carboniferous Echinoid from North America

By PORTER M. KIER

ABSTRACT

A new species of *Palaeechinus*, and the first certain member of that genus from North America, is described and several unusual features of its test noted. The apical disc of the specimen is extremely well preserved.

INTRODUCTION

THE discovery of a new species of *Palaeechinus* from North America is significant not only as it represents the first confirmed member of that genus yet found there (*P.* ? *minor* Jackson from Burlington, Iowa, may be a *Maccoya*) but also as it provides another step in the morphological succession of the family. The echinoid was collected in British Columbia and presented to the Sedgwick Museum, Cambridge, by P. K. Sutherland, to whom I am indebted. I also want to thank A. G. Brighton for his criticism and suggestions.

Family PALAEECHINIDAE M'Coy

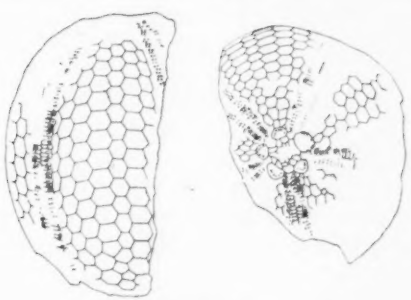
Genus **Palaeechinus** M'Coy

Palaeechinus M'Coy, 1844, p. 171

Genotype.—By subsequent designation, *Palaeechinus ellipticus* M'Coy, Lambert and Thiéry, 1910, p. 119.

Palaeechinus canadensis sp. nov.

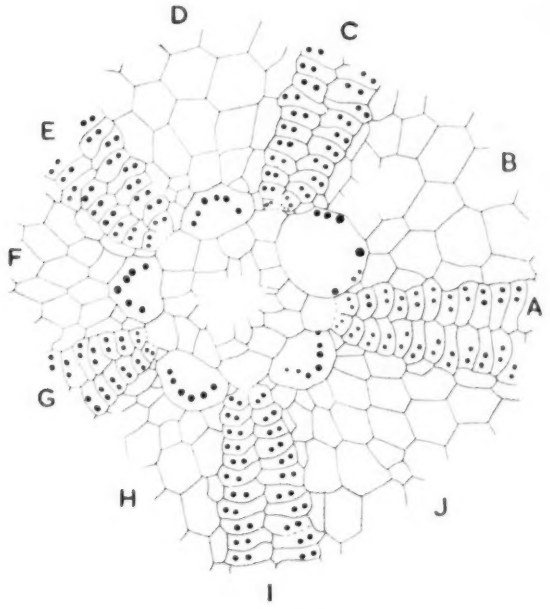
Diagnosis.—This species is characterized by an elliptical test, and by ambulacral plates which are primaries at the midzone but are alternately narrowed and broadened at their margins. There are eight interambulacral columns at the midzone. Only one specimen, the holotype, was found, which is in the Sedgwick Museum, No. E 14403.



TEXT-FIG. 1.

Description.—The test is high, elliptical, measuring 34 mm. in diameter through the midzone, and was probably about 43 mm. high when complete. At the midzone, the ambulacra are 4·5 mm. wide and the interambulacra 16 mm. wide. The adradial suture is depressed throughout the length of the ambulacra with the interambulacra more inflated than the ambulacra.

Apical Disc.—The apical disc is well preserved with the sutures quite clear (Text-fig. 2). Four of the five genitals are of equal size and are



TEXT-FIG. 2.

pierced by six, or in genital J, seven pores which occur in a line parallel to the adoral suture and well within the plate. The fifth genital, B, however, is approximately twice as large as the other four and its seven pores are immediately adjacent to the adoral suture. While the large size of this plate might be indicative of a madreporite, no fine madreporitic pores are visible and I am quite certain, considering the excellent preservation of the specimen, that they were never present.

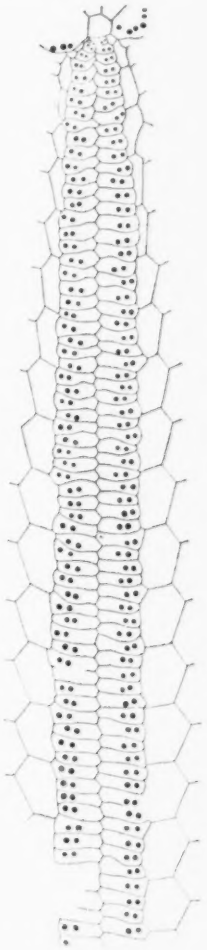
The five oculars are small, imperforate, insert, and are depressed at the ambulacral margins and tilt up to the periproct. It is of particular interest to note that ocular A does not come in contact with any plates of interambulacral column B. Jackson reported similar occurrences in oculars of *Lovenechinus lacazei* (Julien) and *Melonites*

multiporus (Norwood and Owen), but considered this to be the result of displacement during fossilization (Jackson, 1912, pp. 62, 86, 328, 334, 363 ; see also Bather's illustration in Jackson, 1912, of *Lovenechinus lacazei*, text-fig. 243, p. 331.) However, in this specimen there is no displacement visible and it is quite obvious that it is an original condition probably due to the enlargement of genital B.

While this condition is unusual, there is on reason why it should have presented difficulties in the growth of the echinoid. More interambulacral plates could still be produced in the ocular area and by resorption of part of the genital and adjacent ambulacral plates these new plates could move ventrally.

The plates of the periproct in the first circlet within the oculo-genital ring are thick, large, and polygonal, very like those found in *Palaeechinus elegans* M'Coy and *Maccoya sphaerica* (M'Coy) (Jackson, 1912, pl. 31, fig. 4 ; pl. 34, fig. 6). The plates of the circlet within this circlet are long, were probably pentagonal, and radiate out from the centre of the area. Similar plates are present in *Melonechinus chuseni* Chao, 1942, p. 202, text-fig. 1.

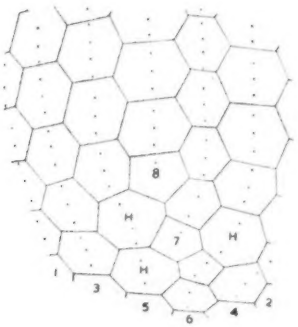
Ambulacra.—The ambulacra (text-fig. 3) are narrow with two columns of primary plates in each area and with five or six plates equal to the height of an adambulacral ; pore pairs are irregularly uniserial. Near the apical disc, the ambulacral plates curve adapically near their peradial sutures. At the midzone, though all the plates are primaries, they are alternately narrowed and broadened at their adradial margins and the pore pairs are almost biserial, the outer pore of one plate being almost in line with the inner pore of the succeeding plate. Therefore according to the structure of the ambulacra, this species is morphologically the most advanced species of the genus.



TEXT-FIG. 3.

Interambulacra.—The interambulacra are wide with eight columns of plates at the midzones. The adambulacral plates are typically

pentagonal and higher than wide ; whereas, the plates of the median columns are hexagonal and at the midzone as wide or wider than high, with the exception of each column to the right of centre in which the plates are very high and narrow. This condition was observed in all of the three interambulacral areas that are preserved at the midzone. As the adoral portion of the specimen is missing, it is possible to observe only the terminal plate of column 8 and in area J, column 7. In areas J and D, column 8 occurs left of centre, not right of centre as typical of the even-numbered columns in the species of this family



TEXT-FIG. 4.

(Jackson, 1912, p. 68), and is introduced by the usual pentagonal plate with a heptagonal plate on the left in the preceding column. In area D (Text-fig. 4), an unusual plate arrangement is present with the pentagonal terminal of column 7 preceded by a pentagonal plate in column 6 with two heptagonal plates on either side.

The adambulacral columns 1 and 2 of area J, 2 of H, and 1 of B (Text-fig. 2) do not reach the apical disc but drop out adapically with columns 3 or 4 assuming the adambulacral position.

Ornamentation.—The plates of the test bear the numerous secondary tubercles so common in the *Palaeechinidae*. There are approximately thirty tubercles on each interambulacral plate and three or four on each ambulacra plate. Of special interest are the tubercles which occur on enlarged genital B. Each tubercle is surrounded by a scrobicular ring of approximately sixteen miliaries. This is the only instance of a scrobicular ring occurring in the family (Jackson, 1912, p. 332).

Remarks.—P. canadensis is distinguished from all the other species of *Palaeechinus* by its eight interambulacral columns. It is distinguished from all the species of the genus *Maccoya* by its primary ambulacral plates and uniserial pore pairs. The specimen is from a limestone bed that is believed to correlate with the Banff formation of Alberta and is equivalent in age to either Upper Kinderhookian or Lower Osagean

in North America or the Tournaisian of Europe (Weller *et al*, 1948, Chart No. 5). This species occurs in its expected geological position as it was found in rocks older than those in which its morphological successors, the genus *Maccoya*, are found (see Mortensen, 1935, pp. 34–5).

Locality.—Kakwa–Jarvis Lakes area, North-East British Columbia, Canada. Found in place on south ridge of first mountain north of Mt. Hannington in thin-bedded, fine grained limestone about 325 feet above contact with Upper Devonian limestone. Geological Survey of Canada, loc. No. 15956 ; Field loc. n. 390. Estimated location ; 54° 9′ north lat. ; 120° 10′ west long. ; about 3·5 miles west of British Columbia–Alberta boundary. Collected by P. K. Sutherland and L. D. Burling of the Phillips Petroleum Company in September, 1945.

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SEDGWICK MUSEUM,
CAMBRIDGE.

CORRESPONDENCE

THE GREAT GLEN CRUSH BELT

SIR,—I am pleased that my little paper on "Mylonite, Slickensides, and the Great Glen Fault" (*Geol. Mag.*, 1951, p. 423) has had the desired effect of drawing from Messrs. Eyles and MacGregor some hitherto unpublished data bearing on the structure of that region. My intention, in writing that paper, was to demonstrate the inadequacy of the evidence relating to mylonite which Kennedy advanced in support of his conclusion that "the predominant displacement along the Great Glen Fault was horizontal" rather than vertical, as Horne and others had supposed. The new evidence is valuable in itself, but it does not help us to distinguish between these possibilities because mylonite may be generated by movement in either direction. As I wrote in my paper, "It is not enough to say that mylonite has been found" without trying to determine the direction of movement, which is the only thing that matters. Elsewhere in my paper I said that the evidence about Loch Oich and Loch Lochy "suggests collapse of the sandstone into a fault-trough". Is there anything in the new evidence to dispose of that possibility?

If Eyles and MacGregor will read Kennedy's paper more carefully, they will see that he referred to a zone of crushed rocks *within* the Glen, because he wrote "Most of this zone is concealed by the deep superficial deposits of the Glen or the waters of the lochs". My comment on the scarcity of mylonite in this zone is not invalidated by discoveries made beyond the bounds of the Glen.

S. J. SHAND.

UNIVERSITY CLUB,
EDINBURGH.
6th December, 1952.

"ASSOCIATION POUR L'ÉTUDE GÉOLOGIQUE DES ZONES PROFONDES DE L'ÉCORCE TERRESTRE"

SIR,—May I bring the following matter to the notice of your readers:—

During the course of the 19th Geological Congress held in Algiers during last September, it was proposed that there should be formed an "Association for the Geological Study of the Deep Zones of the Earth's Crust". A provisional committee was formed comprising—

Prof. P. Michot, Université de Liége.
Prof. E. Raguin, École des Mines, Paris.
Prof. M. Roques, Université de Clermont-Ferrand.
Prof. E. Wegmann, Université de Neuchatel.
Prof. J. G. C. Anderson, University College, Cardiff.

It should be explained that it is not the aim of the proposed Association to study the deeply-buried parts of the earth's crust by geophysical methods, but to investigate rocks formed by deep-seated processes and now exposed. For the present, at any rate, the main function of the Association would be to arrange excursions, under the leadership of one or more members, to districts where such rocks may be readily studied by normal geological methods.

At Algiers about fifty geologists signified their willingness to join such an Association. Other geologists who wish to join are invited to send their names and addresses either directly to Prof. M. Michot, Université de Liége, Belgium, or through the undersigned.

J. G. C. ANDERSON.

UNIVERSITY COLLEGE,
NEWPORT ROAD,
CARDIFF.
18th December, 1952.

REVIEW

EARTH WAVES. By L. DON LEET. Harvard Monographs in Applied Science, No. 2. Harvard University Press, 1950. Price $3.00.

To the student of geophysical prospecting, as to the geologist and the seismologist, a knowledge of the phenomena and the mode of propagation of elastic waves is essential; for experimental work using controlled explosions the principles governing the operation of seismographs have to be clearly understood. These topics are treated by Prof. L. Don Leet in a stimulating and sometimes provocative monograph.

The emphasis is on the explosion technique for investigating the sub-surface layering; the standard methods of estimating depths of discontinuities and the associated wave velocities, as well as the dips of the discontinuities, are well discussed in some detail, particularly in relation to explosion records. The author makes clear the relevance of the instrumental study of earthquakes to the methods of seismic prospecting.

To this extent the book should be helpful to students of geophysical prospecting. There is, however, a serious lack of balance in the contents. For instance, the familiar elementary theory of the integration of the linear differential equation of the forced oscillations of a horizontal pendulum is set out in great detail, although it is to be found in many text-books of physics; yet only a passing reference is made to the form of the simultaneous differential equations that govern the performance of seismographs with galvanometric registration. Again, the discussion of surface waves is very sketchy and, indeed, misleading, for it is not mentioned that Love waves (and Rayleigh waves, in actual practice) are strongly dispersive, and that the energy corresponding to any period is propagated with the appropriate group-velocity—neither "dispersion" nor "group-velocity" is in fact mentioned. The author refers to the "coupled wave" and the "hydrodynamic wave" that he claims to have found in explosion records (and in particular that of the Bikini atomic bomb), but the student is not led to appreciate what criteria must be satisfied before the independent existence of a new type of wave can be regarded as established. It is a pity, indeed, that more emphasis has not been laid on the distinction between the long trains of uniform waves to which the laws of reflexion, refraction, and energy partition are applicable and the pulses actually observed in seismic records, for which a diffraction theory is needed and with which a ray-path cannot always be associated. The volume concludes with a sketch of some aspects of the controversial subject of microseisms.

The typography of the book is good, and the diagrams well-chosen and informative; the problems that arise in interpreting explosion records are indicated in relation to a whole set of records rather than a single one. Misprints are very few. There are some errors that could easily be corrected. Thus, John Milne is referred to as "a British physicist who became one of the founders of modern seismology while teaching in Japan"; a perusal of the article "Eminent Living Geolgists—Professor John Milne" (*Geol. Mag.*, xlix, 1912, pp. 337–46) will show that he went out in 1875 as consulting engineer to the newly-formed Public Works Department of the Japanese Government, became interested at once in the study of earthquakes, and was the first holder of the Chair of Seismology at the Imperial University. Of Lord Rayleigh's classical eight-page paper in the Proceedings of the London Mathematical Society on what are now called Rayleigh waves, Prof. Leet says (p. 46) "Included among early volumes on the theory of elasticity and elastic waves was a treatise published in 1885 by Lord Rayleigh . . .". Again, the statement (p. 58) of Fermat's Principle is rather misleading. But these blemishes are relatively small and do not detract from the usefulness of the book to students of geophysical prospecting.

R. S.

PUBLICATIONS RECEIVED

Permian Fossils from Southland. By H. O. Fletcher, Dorothy Hill, and R. W. Willett. *New Zealand Geological Survey, Pal. Bull.* 19 (4to, 30 pp. with 5 pls.), 1952. Price 5*s.* (paper cover).

Early Tertiary Penguins of New Zealand. By B. J. Marples. *Ibid., Bull.* 20 (4to, 66 pp., with 8 pls.). 1952. Price 9*s.* (paper cover).

The Greymouth Coalfield. By Maxwell Gage. *New Zealand Geological Survey, Bull.* 45 (4to, vol. 1, text, 232 pp., with xii tables and 18 figs. ; vol. 2, 13 folding maps), 1952. Price (bound), text, £2 5*s.*, maps £1 15*s.*, maps and text, £4.

Mineria : Organo del Instituto de Ingenieros de Minas del Peru. Ano 1, No. 1, 63 pp. Lima, 1952.

Nyasaland Protectorate : *Annual Report of the Geol. Survey Dept.* for 1951 (with 5 pls.). Zomba, 1952. Price 4*s.*

Transactions of the Edinburgh Geological Society : vol. xv, CAMPBELL VOLUME. pp. viii + 414, with 11 plates. Oliver and Boyd, Ltd., Edinburgh, 1952. Price 30*s.*

Papers of the Michigan Academy of Science, Arts and Letters. Vol. xxxvii (1951). 513 pp. University of Michigan Press, Ann Arbor (London, Geoffrey Cumberledge), 1952. Price 72*s.* (Containing papers on Caribou remains in Pleistocene, by Claude W. Hibbard ; Pre-Cambrian rocks near Gardiner, Montana, by W. H. Parsons and E. L. Bryden ; and Radioactive dinosaur bones from Wyoming, by K. G. Smith and D. A. Bradley).

Volumetric and Phase Behavior of Oil Field Hydrocarbon Systems. By M. B. Standing. pp. vi + 123, with 69 figs. Reinhold Publ. Corp., New York (London, Messrs. Chapman and Hall), 1952. Price 80*s.*

An Introduction to Historical Geology. By W. J. Miller. 6th Edn. pp. ix + 555, with 404 figs. Van Nostrand Co., New York (London, Macmillan and Co.), 1952. Price 42*s.*

ANNOUNCEMENT

SPECIAL UNIVERSITY LECTURES IN GEOLOGY, UNIVERSITY OF LONDON

A course of three lectures on *The Tectonics of North Africa* will be given by PROFESSOR P. FALLOT (Collège de France, Paris) at Birkbeck College, Malet Street, London, W.C. 1, on 23rd, 24th and 27th February, 1953, at 5.30 p.m. The Chair at the first lecture will be taken by Dr. W. Campbell Smith.

Admission free, without ticket.

CROWN AGENTS FOR THE COLONIES.—Prospector required by the Government of Sierra Leone for the Geological Survey Department, for a tour of 18 to 24 months in the first instance. Commencing salary according to age in scale £867 rising to £1,022 a year (including allowances). Gratuity of £25 for each 3 months' service. Outfit allowance £60. Free passages. Liberal leave on full salary. Candidates should have had previous experience of Pre-Cambrian Terrains and be prepared to remain for long periods in the bush. They must be able to supervise deep trenching and pitting; sharpen hand drills and do simple blacksmithing; train hand drillers; blast and train blasters; drive winze and rise in field conditions; make small simple windlasses; splice wire and vegetable fibre ropes; recognize commoner economic minerals; pan and trace outcrops by loaming and following float; take rough samples and estimate valuable contents by panning; read simple maps and use a compass. Apply at once by letter, stating age, full names in block letters and full particulars of qualifications and experience, and mentioning this paper to the Crown Agents for the Colonies, 4 Millbank, London, S.W. 1, quoting on letter M. 27797 E. The Crown Agents cannot undertake to acknowledge all applications and will communicate only with applicants selected for further consideration.

WANTED

Copy of *Geological Magazine* published in 1923, pp. 226–237, containing article by Teale and Campbell-Smith, "Nepheline-Bearing Lavas and Intrusive Rocks from South of the Zambesi River, Portuguese East Africa." Reply to Eastern Gulf Oil Co., Ltd., 75 Brook Street, Grosvenor Square, London, W. 1.